SUBWATERSHED MANAGEMENT PLAN

FOR

BELLINGHAM, MA

Produced by

Charles River Watershed Association

and Nitsch Engineering Inc.

for

The Town of Bellingham, Massachusetts

Supported by

Massachusetts Department of Environmental Protection

August 2011

CRWA

Nitsch Engineering

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MassDEP

TOWN OF BELLINGHAM MASS. INCORPORATED NOV. 27, 1719

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INTRODUCTION

Like many municipalities in eastern Massachusetts, the Town of Bellingham faces significant water resource challenges. Traditional development patterns and infrastructure designs have altered the environment, disrupting the natural hydrologic cycle and creating unanticipated problems town planners and engineers must now solve. Local aquifers, the source of all of Bellingham's water supplies, are stressed in summer months, leading to outdoor watering bans and creating challenges for future growth. Base flows in local rivers and streams, which depend on the same aquifers, often drop to levels that threaten fish and wildlife, as well as recreation. Vulnerable wetlands, such as vernal pools and headwater streams, are particularly sensitive to the reduction in base flow and are more easily contaminated by stormwater than larger wetlands and rivers. Rainfall, which was once absorbed as it fell by plants or soaked into the ground to fill aquifers, is now drained rapidly off developed land through underground pipes and culverts, creating water pollution, flooding and erosion.

Charles River Watershed Association (CRWA) has been working to understand urban hydrology for the past two decades. In 2005, CRWA launched the *Blue Cities™ Initiative*, a program to develop sustainable urban water resource management and to use redevelopment as the driver for urban watershed restoration. Our goal is to identify techniques and management approaches to reengineer the built environment to make it function more like the natural environment. Our work has demonstrated that sustainable solutions exist, and that by using techniques such as green infrastructure, low impact development (LID), water conservation and reuse, watershed towns can balance their water budgets, protect their ground- and surface water resources, and continue to grow.

Bellingham's water resource challenges are mirrored in cities and towns across the New England region and to some extent across the country. Changing the way water is managed in urban and suburban areas has become a national priority. The Charles River watershed is of particular interest because stormwater runoff has been identified as the main reason the river does not meet water quality standards, leading to a new set of federal regulations that will impact not only municipal governments, but also private property owners throughout the watershed. As a result of a recent Total Maximum Daily Load (TMDL) stydt, the Environmental Protection Agency (EPA) will now require Bellingham to reduce phosphorus loads in its stormwater runoff in order to prevent excessive nutrient pollution and the rapid eutrophication of the Charles River.

CRWA has been working with Bellingham for many years to improve the river and its tributaries, and to help Bellingham protect its water supplies. In 2010, funded by a 604(b) planning grant from the MA DEP, CRWA began work on a Subwatershed Management Plan for Bellingham in partnership with Nitsch Engineering, Inc. (NEI) and Bellingham town officials to develop a plan for an area in Bellingham that would restore water quality, reduce flooding and erosion, and comply with new and emerging stormwater regulations, particularly the TMDL for Nutrients in the Upper/Middle Charles River, Massachusetts (CRWA, 2009) and MassDEP Wetland and 401 regulations.

This Plan is the result of that project. It demonstrates the feasibility of complying with regulations and managing stormwater runoff using a combination of small scale local practices with larger scale, regional stormwater projects. Bellingham town officials worked closely with CRWA and NEI throughout the development of this plan, helping identify areas and types of designs that would be most feasible. The biggest challenges for the Town are financial: funding a town wide stormwater management program, including the construction of numerous stormwater treatment systems, will take time and will require public outreach and education. However, as this project affirms, it is technically feasible and would help Bellingham not only to meet its regulatory requirements but also to increase groundwater recharge, reduce flooding, and improve the public realm.


The Charles River in Bellingham, MA.

COMMUNITY SETTING

Bellingham is a community of aproximately 16,000 residents covering 18.55 square miles in the ex-urban area surrounding Boston. With the northern half of Bellingham in the Charles River Watershed and the southern half in the Blackstone River Watershed, the Town originally developed around industrial uses as a secondary mill town driven by the availability of hydro-power. Today, the Town, while primarily residential, maintains ties to its commercial and industrial-based past. Bellingham is of particular interest to CRWA because of new stormwater regulations proposed by EPA to require existing large industrial, commercial and high-density residential developments to effectively manage stormwater runoff from their properties to ensure they are complying with the requirements of the Upper/Middle Charles River Nutrient TMDL. Presently, Bellingham is subject to EPA's Phase II MS4 General Stormwater Permit.

Bellingham Town Hall.

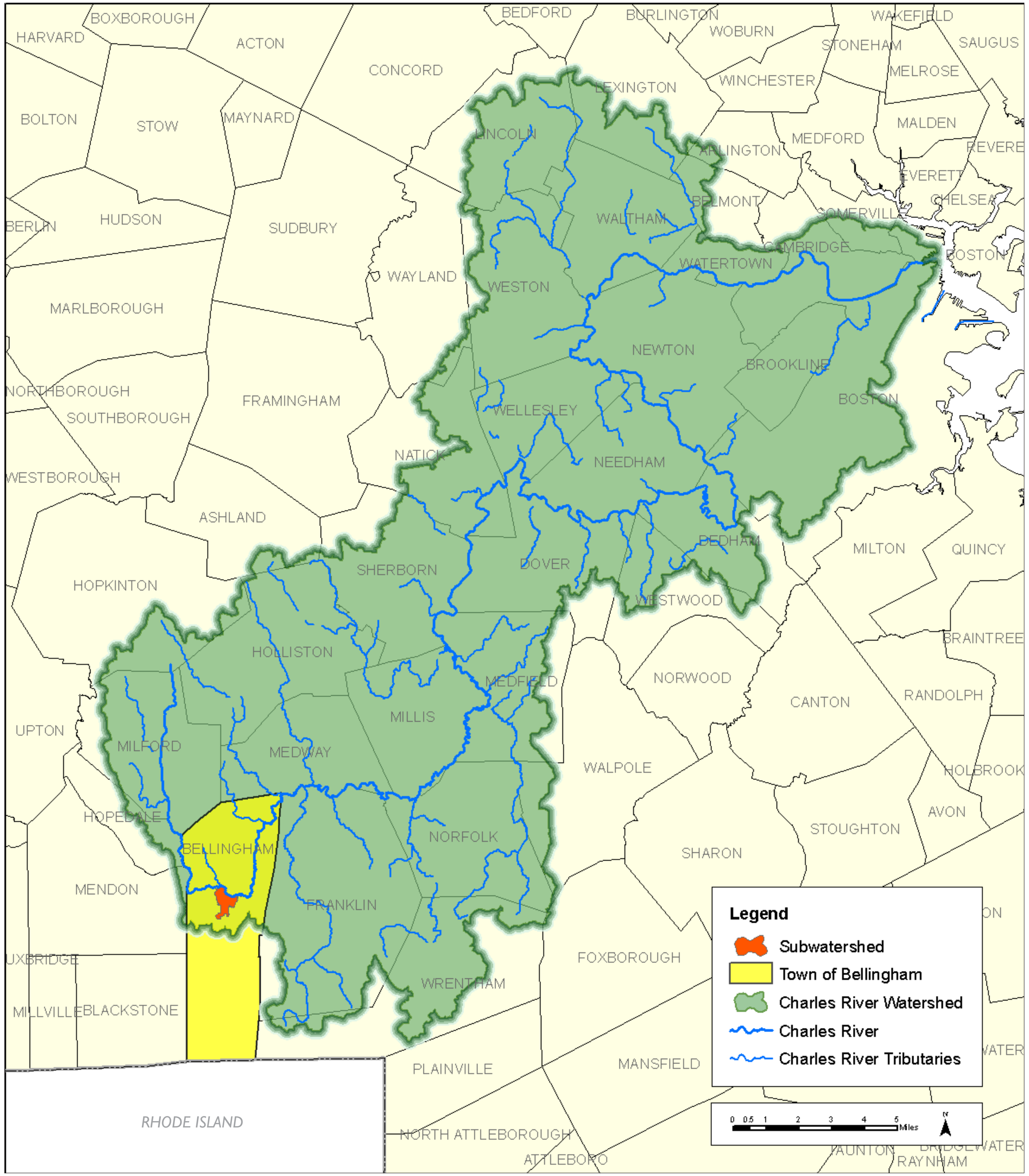


Figure 1 . Subwatershed in Bellingham, MA, highlighted in red, within the context of the Charles River watershed

STUDY AREA SELECTION

CRWA's first task was to identify and select an appropriate area for which we would develop a stormwater management plan. Our goal was to select an area that met the following criteria:

- Appropriately sized for stormwater modeling within the confines of this project (less than 1/2 square mile);
- Contains mixed land uses, representative of the Town of Bellingham as a whole;
- Includes private properties that will be subject to EPA's new stormwater permitting program (a.k.a Designated Discharge (DD) program);
- Includes public property and open space;
- Has a significant amount of impervious cover;
- Provides retrofit design opportunities of varying types and at different scales;
- Has engaged stakeholder groups.

The first phase of the selection process involved extensive use of geographic information systems (GIS) to assess how various subwatersheds matched selection criteria. The following information was compiled for possible subwatersheds:

- Size
- Population
- Soil types
- Land use (1999)
- Parcel sizes within the subwatershed
- Permitted water withdrawal and discharge points
- Public sites
- Open space
- Stormwater permit sites (a.k.a. DD sites)
- Impervious area

Based on the initial assessment, CRWA narrowed down the number of potential study areas based on the criteria listed above. CRWA then conducted site visits to further evaluate existing conditions, as well as restoration potential and challenges. Following this assessment process, CRWA met with the Town Planner, Department of Public Works, the Department of Health and representatives from Nitsch Engineering to select the final study area. Town personnel provided important input regarding the municipality's plans and priorities for the various areas.

The Bellingham Town Center was selected as the study area because it closely matched the selection criteria. The Subwatershed Selection Report which details the process leading to the selection of this subwatershed can be found on CRWA's website www.charlesriver.org/projects/bellingham/CRWASubwatershedSelectionReport_Final.pdf).

"Our goal is to identify techniques and management approaches to reengineer the built environment to make it function more like the natural environment."

- Charles River Watershed Association

EXISTING CONDITIONS ANALYSIS

Methodology

After selecting Bellingham Town Center as our study area, CRWA collected detailed information on this subwatershed to help select, locate and design environmental restoration techniques and stormwater controls. This assessment included analysis of the subwatershed in the following areas:

- Topography
- Hydrological features
- Infrastructure (stormwater, water and sewer)
- Soil type (HSG)[1]
- Land use and zoning
- Land cover
- Assessor's parcels
- Open space
- Drinking water resource areas
- Wetland resource area locations
- Historical water resources and land uses
- CRWA's previous investigations in this area, including an optimal stormwater recharge investigation
- Existing and new stormwater regulatory programs
- Water quality data
- State water quality assessment categories and listings
- Estimated existing phosphorus load
- Target phosphorus reduction based on Upper Charles TMDL

Analysis was conducted using GIS data obtained from the Town and MassGIS, through site visits and communications with Town personnel and by reviewing CRWA's past data and reports and state and federal water quality assessments and studies, including the Upper/Middle Charles River TMDL.

Results: Project Area Description

The Bellingham study area is located within the Charles River watershed in central Bellingham (Figure 2). The study area is the drainage area for a portion of the mainstem of the Charles River. This subwatershed was delineated by creating two subwatersheds using delineation points defined by tributary confluences with the mainstem. The subwatershed delineated to the more upstream of the two points was subtracted from the area delineated to the downstream point; this defined the drainage area for the subsection of river between the two drainage points. The study area boundary was then further modified based on stormwater infrastructure drainage, parcel boundary lines and by excluding the section north of the river. Parcel boundary lines define the study area boundary where a designated discharge (DD) site spans the natural subwatershed boundary. The study area boundary was modified to either entirely include, or entirely exclude these DD sites, as these sites will be required to manage runoff from their entire site, not selected subsections of the properties.

The study area is 0.37 square miles and is located to the south and west of Route 495, with the intersection of Routes 140 and 126 at its center. The mainstem of the Charles River forms the area's northern boundary. The river is surrounded by wetlands to the south. There are a few additional small wetland areas throughout. Small streams form hydrologic connections between wetland areas and/or between wetlands and the river. Developed land within the study area is drained by underground stormwater drain pipes.

[1] Hydrologic Soil Groups are based on the US Natural Resources Conservation Service classification system, not onsite ground survey

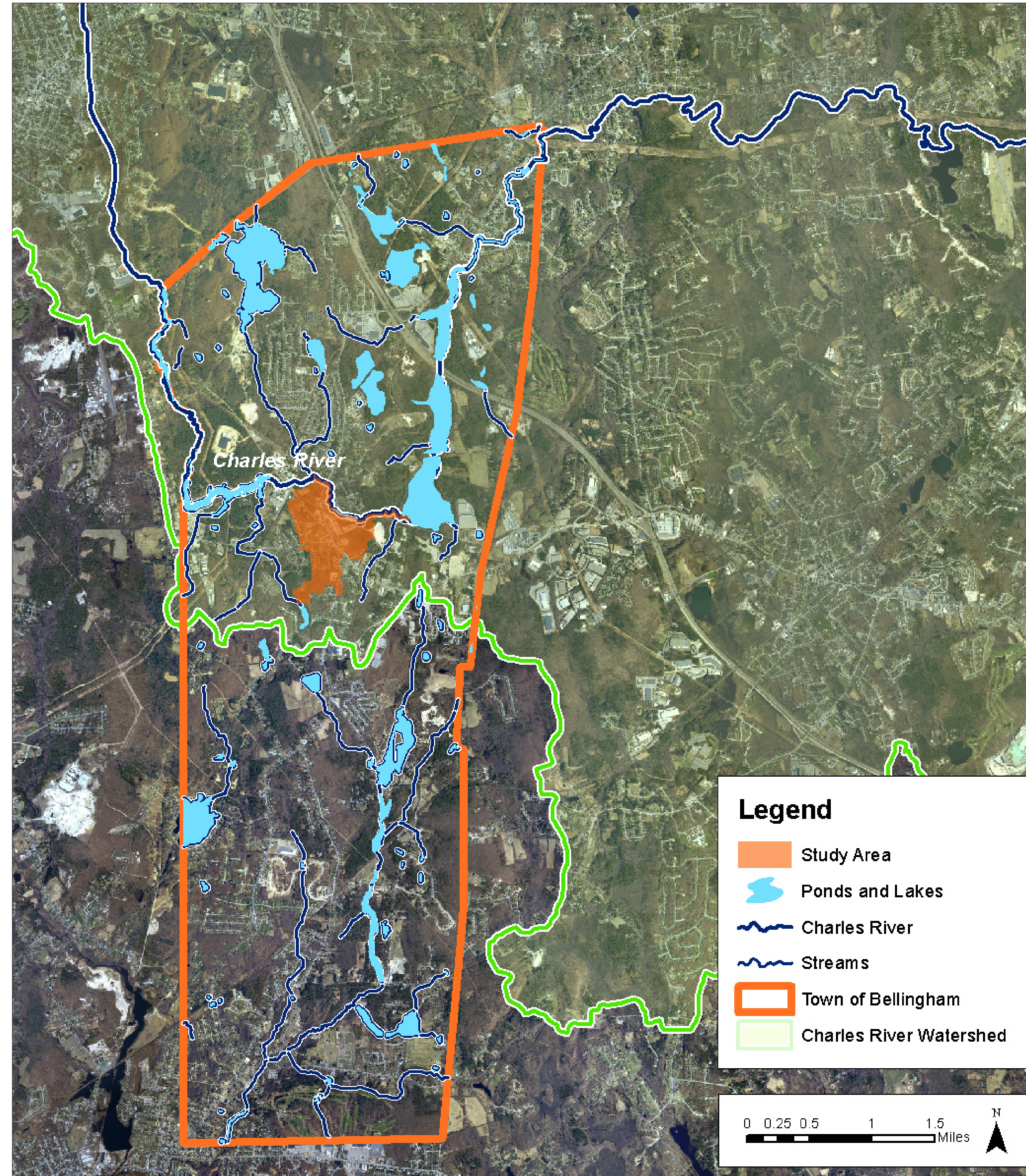


Figure 2. An aerial photograph of Bellingham.

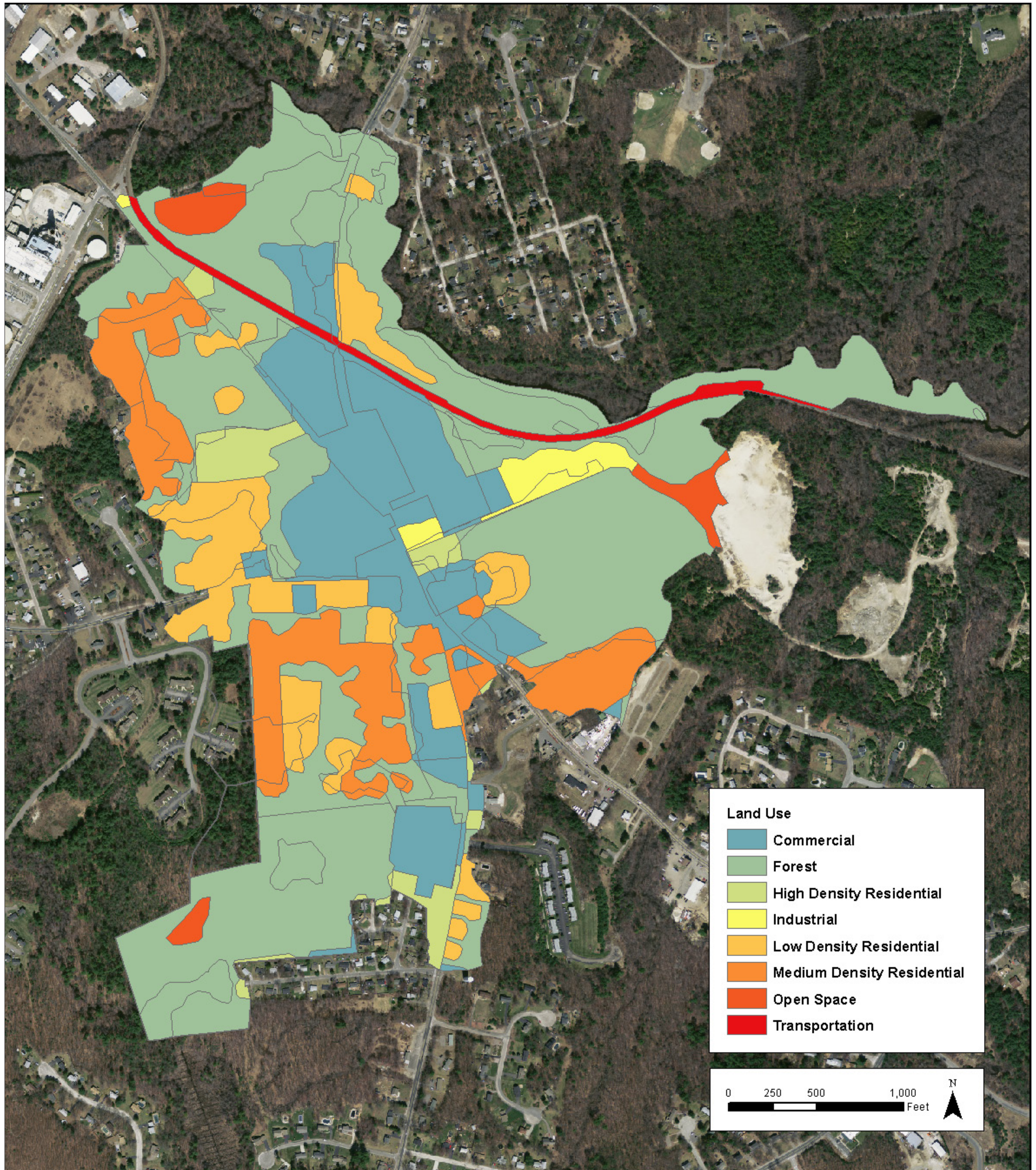


Figure 3. Land use in the study area.

Land use in the study area (Figure 3) is primarily forest (43.1%), followed by commercial (12.5%), and medium density residential (11.8%). Commercial and industrial areas are primarily clustered along North Main St. (Rt. 126). Residential areas are scattered throughout the remainder of the study area. Residential areas are primarily medium- and low-density residential with small areas of multi-family, high density and very low density (See Figure 3).

One of the project goals is to develop a stormwater management plan to bring the study area into compliance with the Upper/Middle Charles River TMDL. To meet this goal, CRWA calculated the required TMDL reduction of total phosphorus for the study area. The target reduction was calculated using the 1999 land use categories from MassGIS and the land-use based target reductions determined in the Upper/Middle Charles River TMDL (CRWA, 2009). This calculation yielded a target phosphorus reduction for the study area of 56% (See Table 1 on page 9). This reduction target is higher than the 52% reduction specified for the overall Town of Bellingham by EPA's National Pollutant Discharge Elimination System (NPDES) Draft General Permit for stormwater because the study area has a higher level of impervious cover than the town as a whole. Since reduction targets are based on land use type, and are driven by impervious cover, specific sub-areas of the Town have different reduction targets than the Town as a whole.

CRWA assumed that a reduction of 15% could be achieved through non-structural stormwater management practices such as street sweeping, catch basin cleaning, leaf litter collection and composting, or discontinuing the use of fertilizers that contain phosphorus. Therefore, the net target reduction goal to be achieved through structural controls is 41%.

PRELIMINARY DESIGN: DIVIDING THE SUBWATERSHED

Methodology

Following the existing conditions assessment, CRWA subdivided the study area further into subareas, called "drainage areas", based on stormwater drainage patterns and stormwater regulations. Industrial, commercial and high-density residential properties with greater than 2 acres impervious area were identified as properties likely to be subject to EPA's pilot stormwater permitting program (a.k.a. Designated Discharge sites). Each of these properties was defined as its own drainage area as the permitting process is designed to mandate owners of these properties to treat their stormwater runoff on-site. The remaining drainage areas were defined by stormwater infrastructure and natural topography. Drainage areas were originally delineated using GIS and further refined based on site visits, consultation with Town personnel and stormwater drainage maps, and preliminary conceptual designs for stormwater control placement. The subwatershed was divided into 29 drainage areas (See Figure 4).

CRWA conducted site visits to each of the 29 drainage areas. Site assessment methodology was based on Center for Watershed Protection's (CWP) Manual 3: *Urban Stormwater Retrofit Practices in the Urban Subwatershed Restoration Manual Series*. Field staff collected data using CWP data sheets, large scale maps, and digital cameras. Information was compiled in a multi-page matrix and library of digital photos. CRWA then selected 6 priority drainage areas (See Figure 5, page 9) for which we would develop full conceptual designs. Priority drainage areas were chosen as a representative subset of the total 29 drainage areas. These drainage areas were selected based on the following criteria:

- Size variability
- Land use variability
- Variability in existing stormwater management (stormwater control present vs. no current treatment present)
- Preference for areas draining to town-owned land
- Preference for areas with a strong public education component (i.e. public parks, recreational fields, etc.)
- One example of sites likely subject to EPA's pilot stormwater permitting program (DD sites)
- Engaged property owner

Information from the subwatershed existing conditions analysis and the preliminary design phase of the project were then combined to produce an existing site conditions analysis for each of the priority drainage areas.

Stormwater management opportunities were also identified for the remaining sites, although conceptual designs were not developed for these sites. See the Modeling Analysis section of this plan for further details.

Results

The next section summarizes the data and field studies obtained through the existing conditions and preliminary design analysis for each of the 7 priority drainage areas.

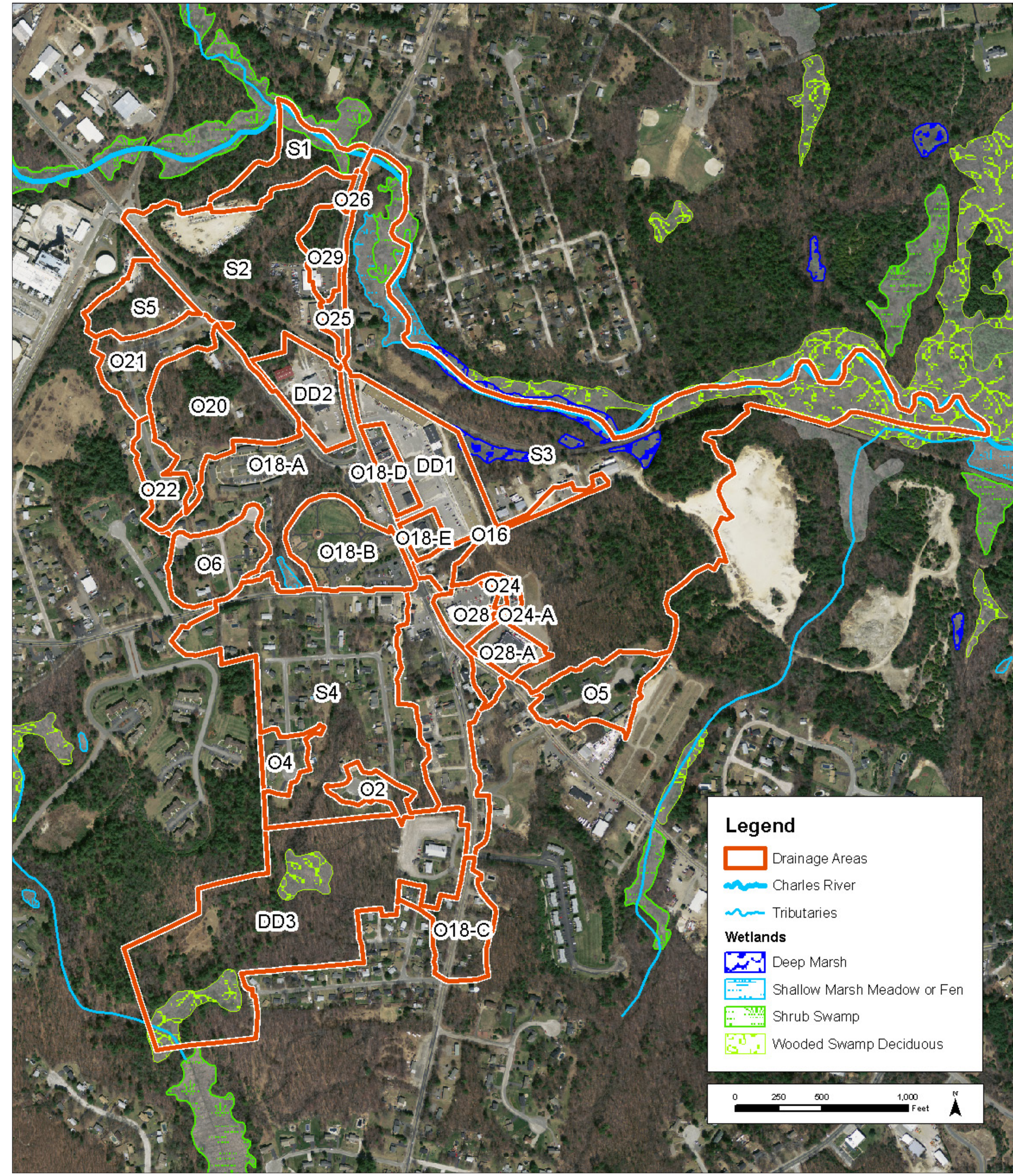


Figure 4. Drainage areas in the study area

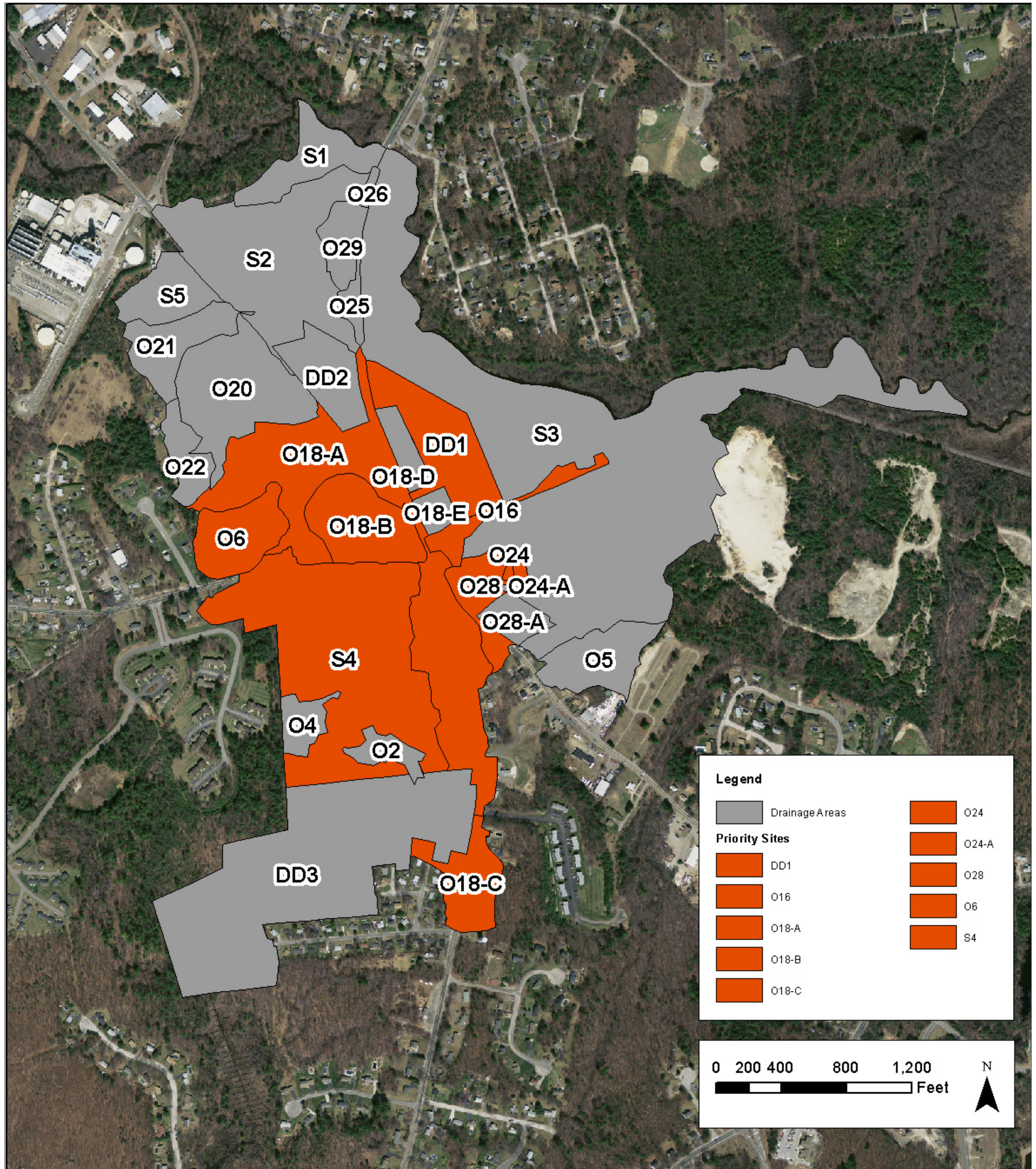


Figure 5. Priority drainage areas in the study area

TMDL Land Use Category	Area in study area (sq. mi.)	Phosphorus Loading (lbs/yr/sq. mi.)	Phosphorus Loading (lbs/yr)	Percent Load Reduction	P Loading Reduction (lbs/yr)	Target Phosphorus Load (lbs/yr)
Commercial	0.02	969.6	17.3	65.0%	11.2	6.0
High Density Residential	0.01	646.1	5.8	65.0%	3.7	2.0
Industrial	0.03	840.0	28.9	65.0%	18.8	10.1
Medium Density Residential	0.08	323.3	27.1	65.0%	17.6	9.5
Low Density Residential	0.03	26.0	0.7	45.0%	0.3	0.4
Open Land	0.03	19.6	0.6	35.0%	0.2	0.4
Forest	0.17	74.4	12.3	0.0%	0.0	12.3
Total	**0.37**		**92.7**		**51.9**	**40.8**

Table 1. Target Phosphorus Reduction for the Bellingham study area

Existing Conditions for Drainage Area DD1-A & B: Bellingham Plaza

Bellingham Plaza is a large, 8.6 acre, commercial designated discharge (DD) site located on the east side of Rt. 126. The plaza is located directly south of the Charles River with steep slopes and mostly impervious surfaces. The development is located below street grade to the east of Rt. 126. There are two retail areas located on the site and there is a grade change of approximately15 to 20 feet between the two areas. A large, bowl-shaped parking lot services the lower retail plaza, the parking area has several catch basins and raised planting beds.

Behind the lower level strip development, there are several downspouts that direct roof runoff to the ground. Storage, trash and road salts/sand collect here. There is a steep, forested drop-off that forms a small valley bordered on the opposite side by railroad tracks, storm water runoff collects in this valley to the south of the tracks.

View towards Main Street (Rt. 126) from Bellingham Plaza parking lot.

View of northern section of Bellingham plaza from adjacent parking lot, at street grade.

Legend

- Drainage Area DD1
- Other Drainage Areas
- Parcel Lines
- Manhole
- Charles River
- Tributaries
- 10 Foot Contour
- Detention Pond
- Inlet
- Outfall
- Drain Pipe
- Catch basins
- Sewer Manhole
- Sewer Pipe

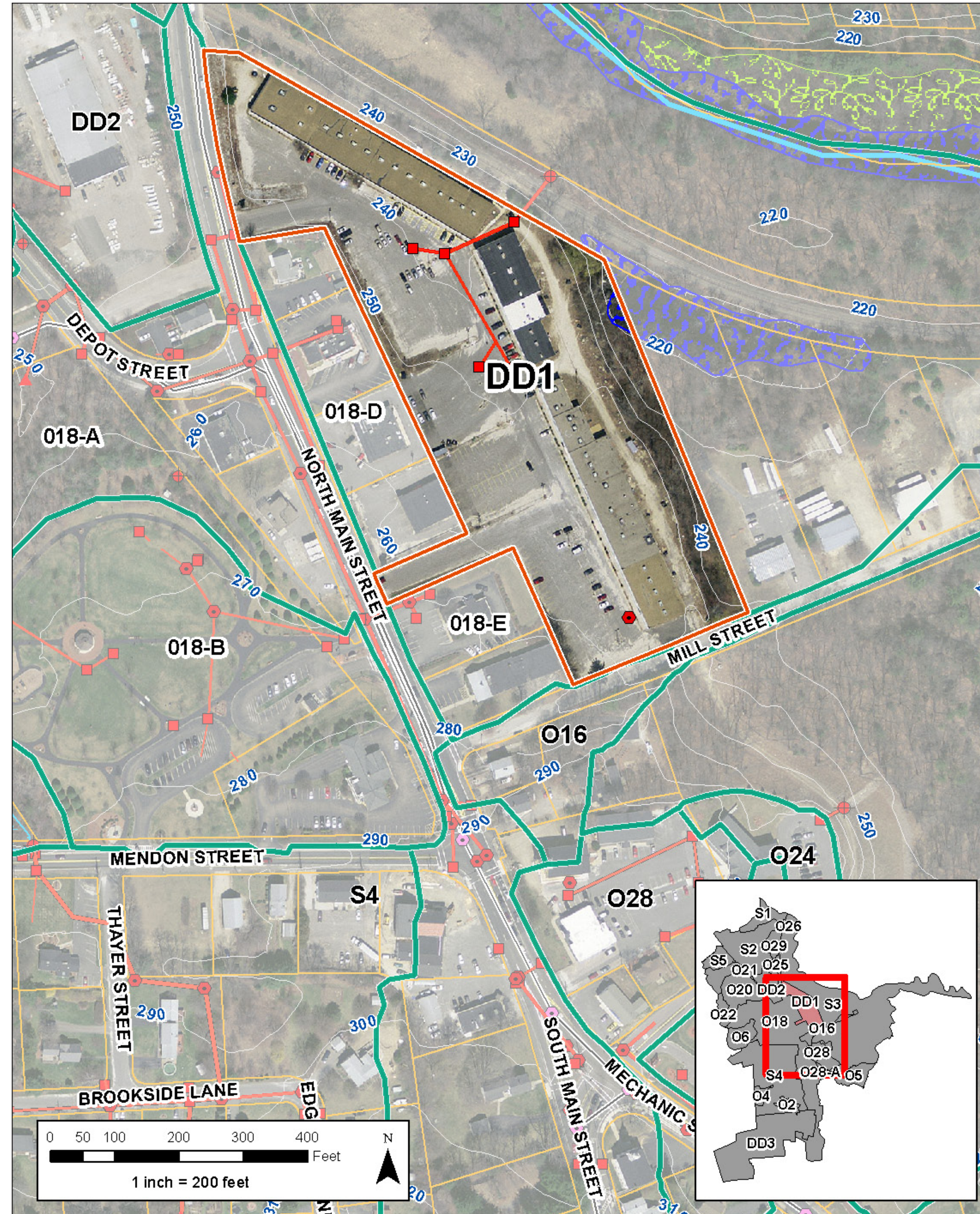
Wetlands

- Deep Marsh
- Shallow Marsh Meadow or Fen
- Shrub Swamp
- Wooded Swamp Deciduous

Site Details

Drainage Areas (acres)	7.6
Impervious Area (acres)	5.7
Land Use	Commercial
Hydrologic Soil Group (at proposed stormwater control site)	A
Existing Phosphorus Load (lbs/yr)	13.2

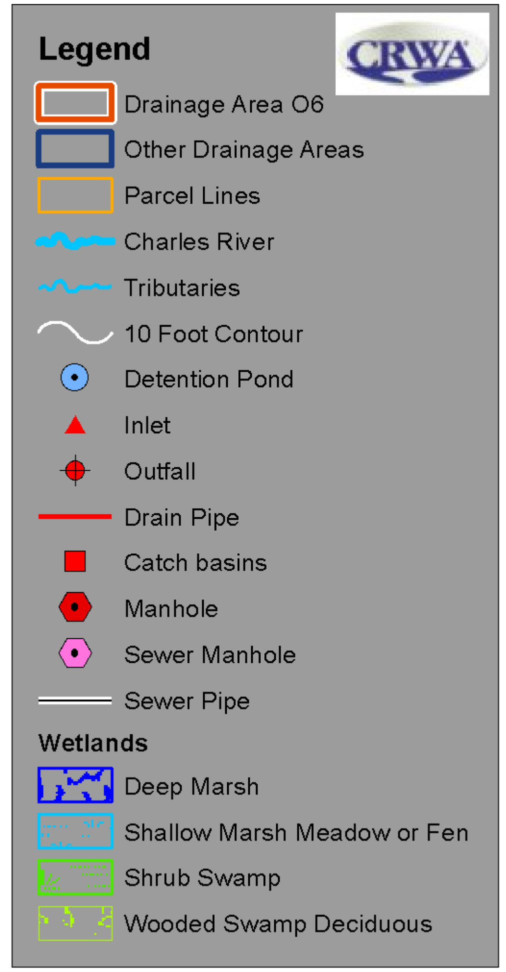
Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA



Toni and Jamie Drive are two streets in a neighborhood consisting of single family residences. This drainage area has less than two acres of impervious surface. Catch basins direct runoff to a large detention pond located on the eastern edge of the drainage area. The pond overflows to a tributary that flows into Drainage Area O18. In the spring of 2011, the detention pond was over run with invasive *Japanese Knotweed* (photo below), posing a serious threat to the adjacent wetlands.


Existing detention pond located in Drainage Area 06

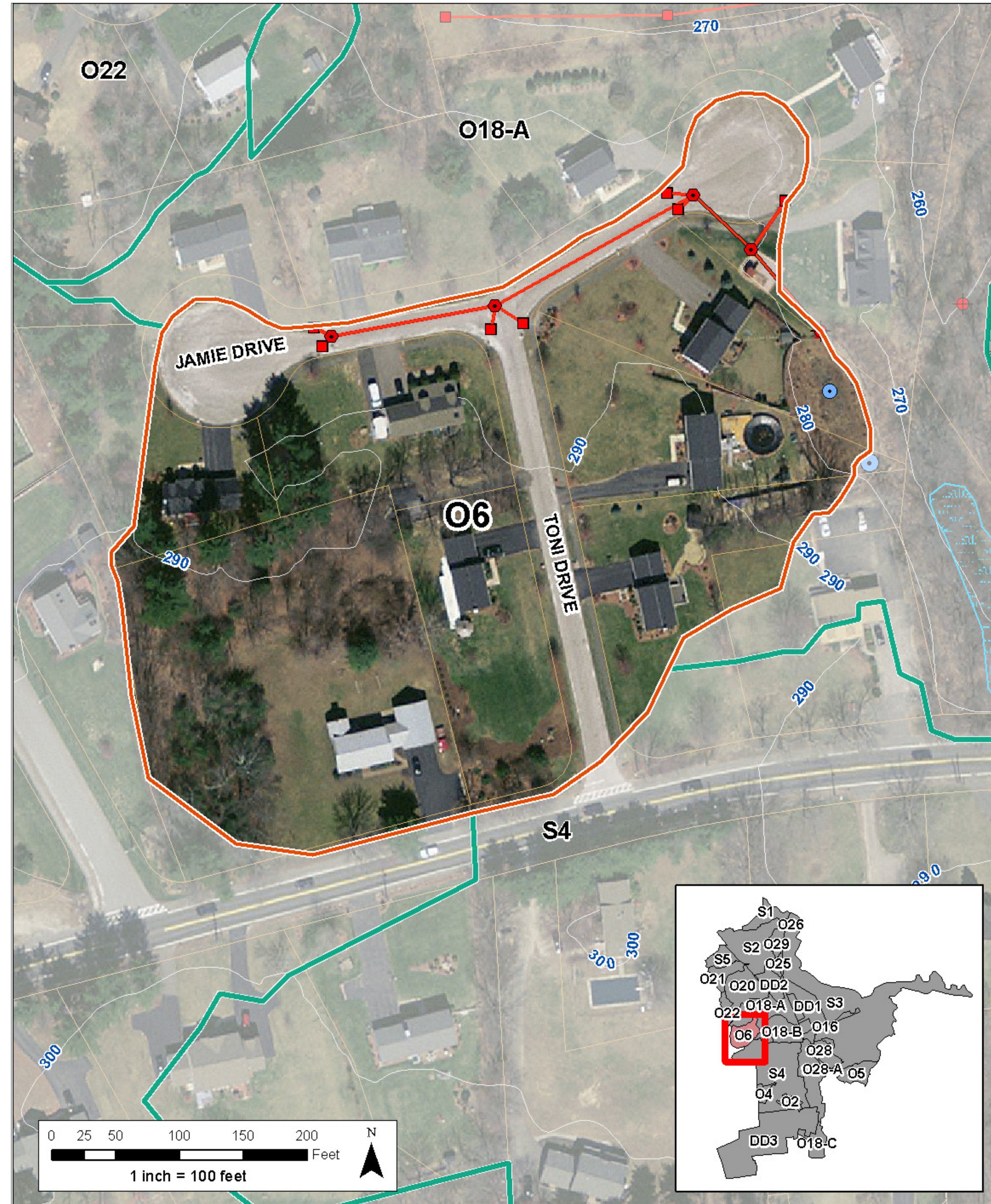

Japanese knotweed, an invasive species, growing in existing detention pond



Site Details

Drainage Areas (acres)	4.9
Impervious Area (acres)	1.2
Land Use	Low Density Residential
Hydrologic Soil Group (at proposed stormwater control site)	B
Existing Phosphorus Load (lbs/yr)	1.5

Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA

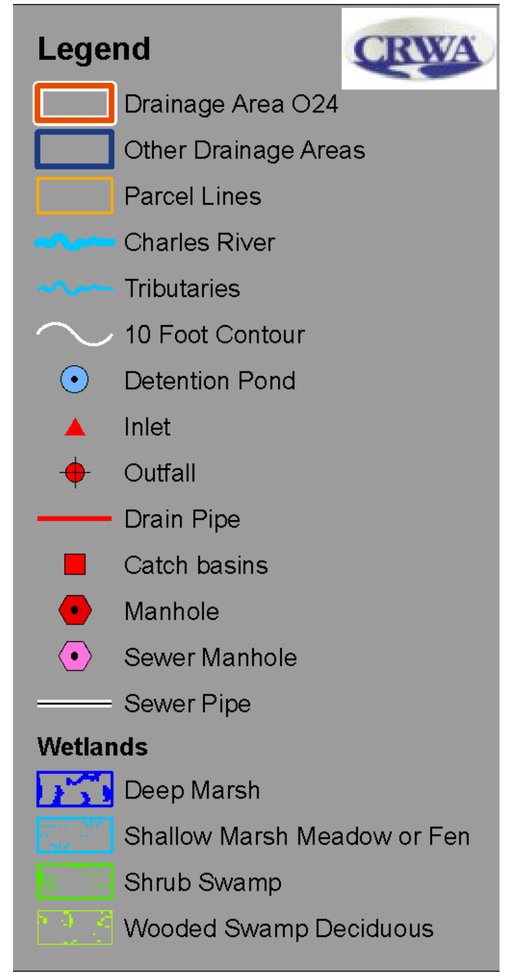


Existing Conditions for Drainage Area O24: Municipal Building Parking Lot

The Town of Bellingham municipal building is located in this drainage area. The building has no gutters or downspouts, but does have a gravel drip edge to receive roof run-off. The grade drops sharply from the front of the building to the back parking area, where several catch basins collect runoff. Drainage from the parking lot is discharged along a rip rap-lined channel at the northeastern edge of the parking lot. Water travels through a forested area before making its way to the Charles.

Rear parking lot and surrounding slope west of Town municipal offices

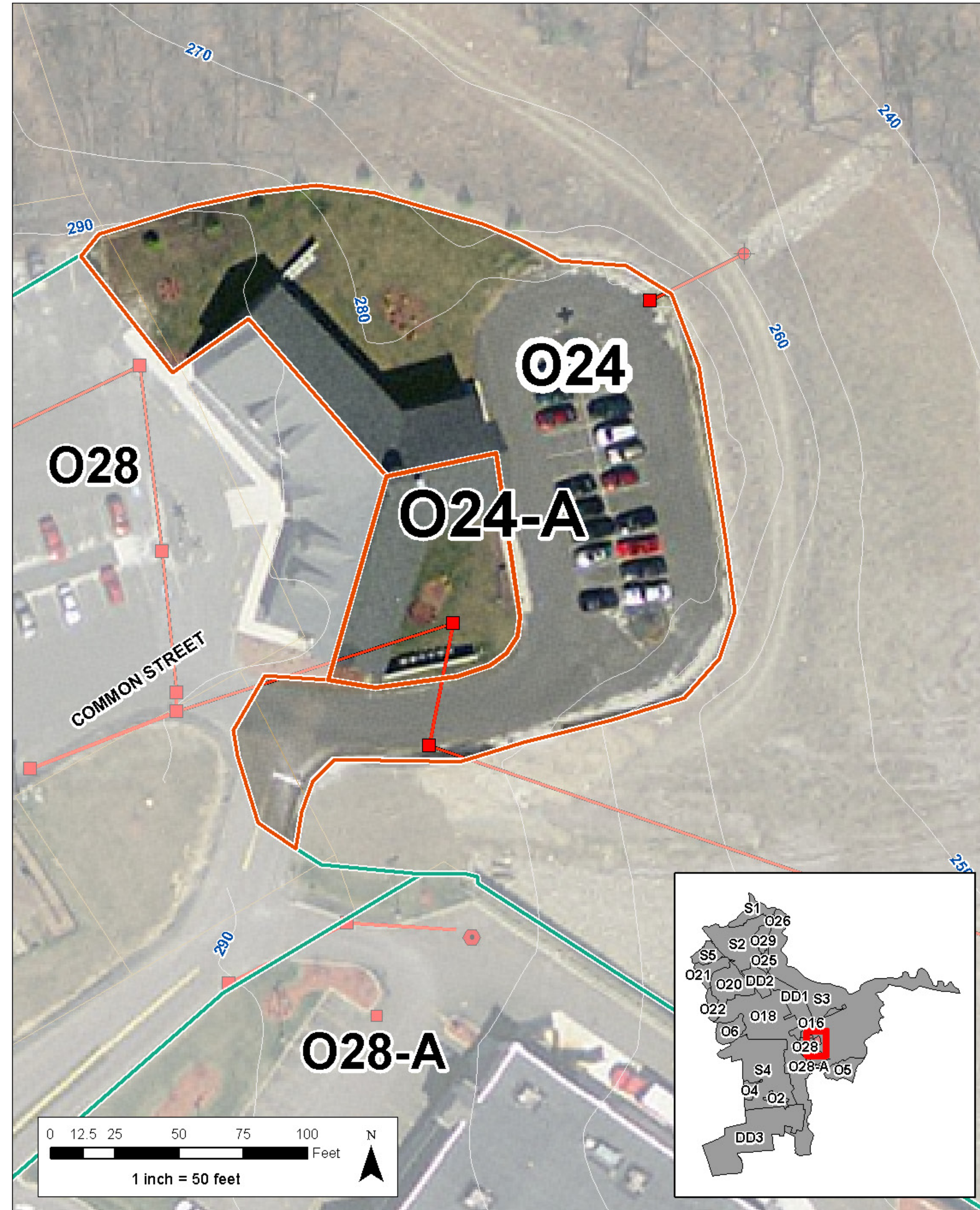
Rear parking lot and view north to surrounding forested slope

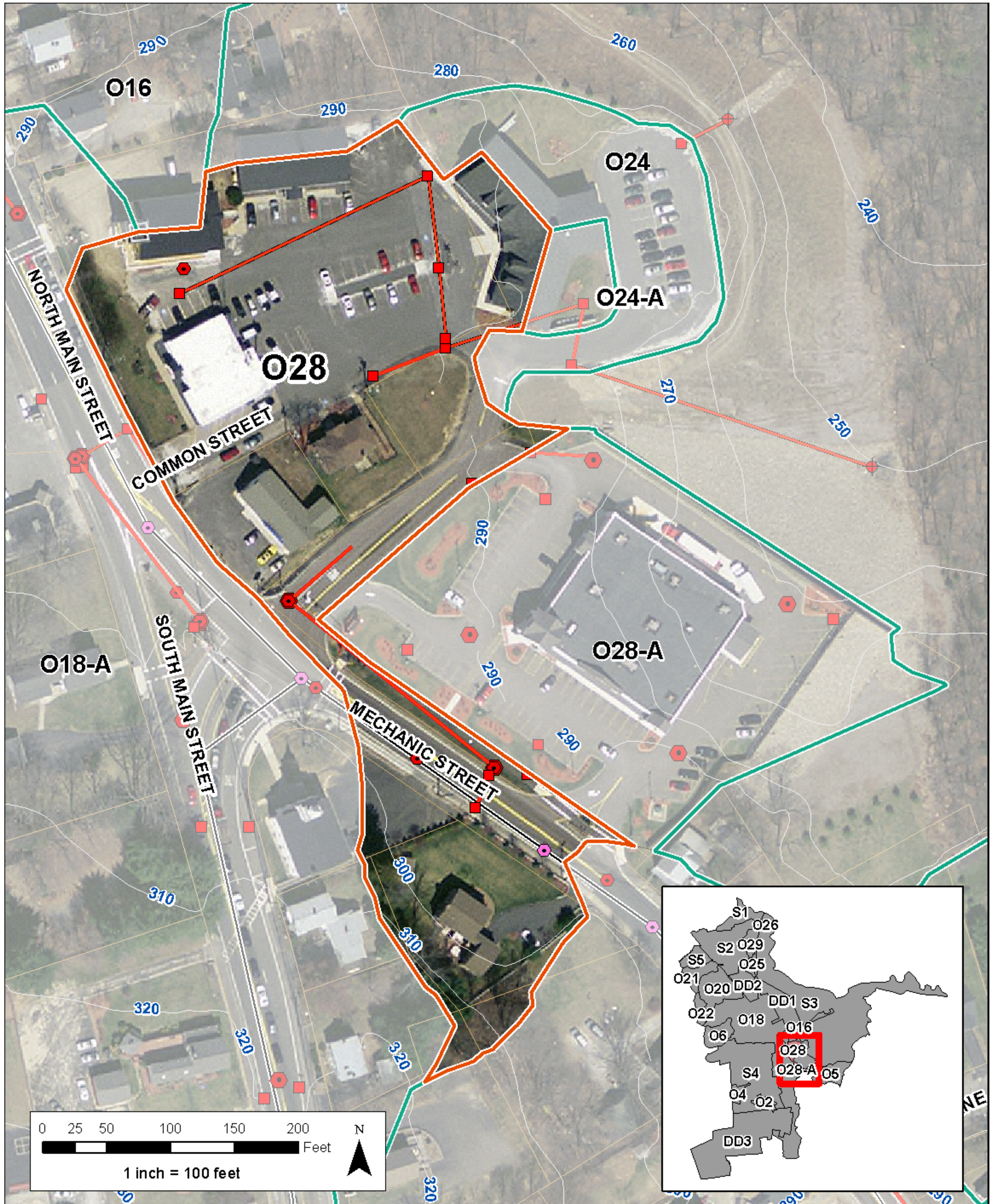


Site Details

Drainage Areas (acres)	0.7
Impervious Area (acres)	0.7
Land Use	Commercial
Hydrologic Soil Group (at proposed stormwater control site)	A
Existing Phosphorus Load (lbs/yr)	0.6

Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA





Legend

- Drainage Area O28
- Other Drainage Areas
- Parcel Lines
- Charles River
- Tributaries
- 10 Foot Contour
- Detention Pond
- Drainage Inlet
- Outfall
- Drain Pipe
- Catch Basin
- Drainage Manhole
- Sewer Manhole
- Sewer Pipe

Wetlands

- Deep Marsh
- Shallow Marsh Meadow or Fen
- Shrub Swamp
- Wooded Swamp Deciduous

This area consists of a town-owned parcel where the Bellingham historic town offices, police station, municipal building and Historical Museum are located. Situated near the intersection of Rtes. 126 & 140, and across from a Walgreens pharmacy, this area sees a lot of vehicular and pedestrian traffic. Most of the site is impervious. The grade drops off steeply behind the buildings and the entry point to most buildings is at-grade, suggesting the potential for flooding at the buildings' entrances.

Water from drainage areas O28 and O24 are directed to two catch basins on the southeastern edge of the parking area. This water is piped to an outfall at the toe of the slope behind Walgreens. Here, water is collected in a small detention pond that is lined with rip rap.

Site Details

Drainage Areas (acres)	3.0
Impervious Area (acres)	2.2
Land Use	Commer-cial
Hydrologic Soil Group (at proposed stormwater control site)	A
Existing Phosphorus Load (lbs/yr)	4.37

Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA

Stormwater runoff from Drainage Area 028 drains to an existing detention pond located down slope from the Walgreens parking lot (DA 028A)

Existing Conditions for Drainage Area S4: Thayer St. Creek Central

This is a large wooded residential area located between the Edgehill Lane cul-de-sac (Drainage Area O2) and the Woodside Lane cul-de-sac (Drainage Area O4). An older residential development is located along Brookside and Thayer Streets. Mapping shows two detention ponds located in Drainage Area S4, which were designed to accommodate runoff from these drainage areas; however, field investigations confirm that only one of these ponds was actually constructed. The constructed pond was observed to be dry following a significant rain event indicating that it is not providing much water quality benefit. The outfall pipe that drains to the area where the second detention pond was proposed to be constructed is severely clogged.

There is a tributary that dissects the Edgehill/Woodside Lane neighborhoods and is routed underground near the Brookside/Thayer Street intersection. Investigators noted residents pumping out wet basements to the storm drain system in this area. Runoff from S4 discharges into a wet area located north of Mendon St. in drainage area O18.

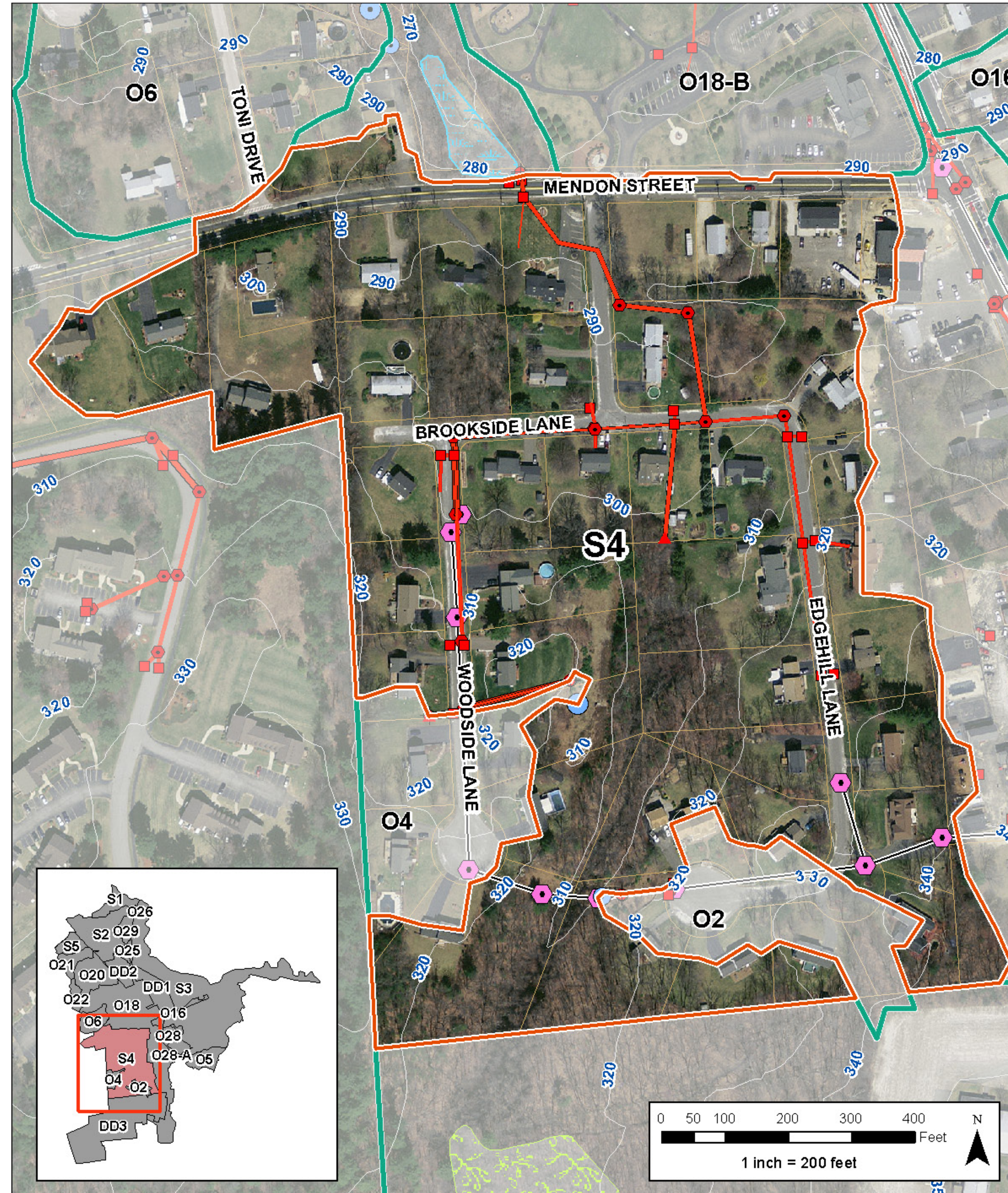
Both Woodside Lane and Edgehill Lane end in paved cul-de-sacs, with houses facing the street and rear yards back by wooded areas.

Legend

- Drainage Area S4
- Other Drainage Areas
- Parcel Lines
- Charles River
- Tributaries
- 10 Foot Contour
- Detention Pond
- Drainage Inlet
- Outfall
- Drain Pipe
- Catch Basin
- Drainage Manhole
- Sewer Manhole
- Sewer Pipe

Wetlands

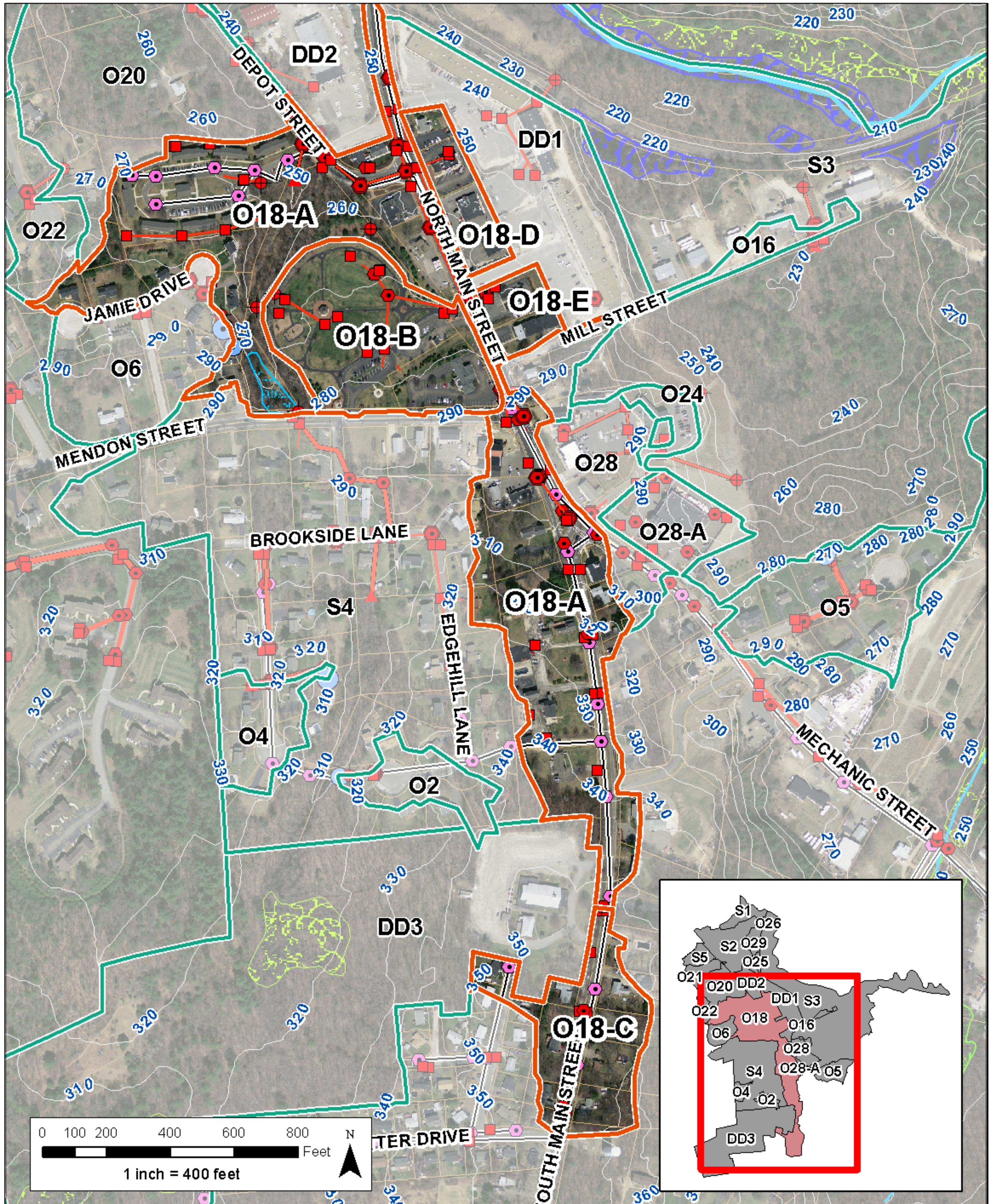
- Deep Marsh
- Shallow Marsh Meadow or Fen
- Shrub Swamp
- Wooded Swamp Deciduous



Site Details

Drainage Areas (acres)	27.0
Impervious Area (acres)	5.6
Land Use	Medium Density Residential
Hydrologic Soil Group (at proposed stormwater control site)	B
Existing Phosphorus Load (lbs/yr)	11.1

Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA



Legend

Drainage Areas

- O18-A
- O18-B
- O18-C
- O18-D
- O18-E
- Other Drainage Areas
- Parcel Lines
- Charles River
- Tributaries
- 10 Foot Contour
- Detention Pond
- Inlet
- Outfall
- Drain Pipe
- Catch basins
- Manhole
- Sewer Manhole
- Sewer Pipe

Wetlands

- Deep Marsh
- Shallow Marsh Meadow or Fen
- Shrub Swamp
- Wooded Swamp Deciduous

Site Details

Drainage Areas (acres)	37.4
Impervious Area (acres)	15.43
Land Use	Commercial
Hydrologic Soil Group (at proposed stormwater control site)	A and C
Existing Phosphorus Load (lbs/yr)	35.41

Data Sources: MassGIS, Town of Bellingham, CRWA, NRCS, EPA

The Commons is a large, predominantly flat park that was developed in 1998. Grassy areas and asphalt walkways are organized around a central gazebo. Water from drainage area S4 (See Figure 4, page 8) flows across Mendon Street northward onto drainage area O18 at its southernmost point. This water forms a stream and continues to move north along the Town Common. Additionally, surface water along South Main St. is captured by underground catch basins and moved to the north via underground pipes to an outfall near Depot Street.

A Bellingham Housing Authority (BHA) complex (eight, 2-story buildings, cul-de-sac formation) is located north of the Commons. There is a small forested area with a walking trail that connects the Commons to these residences. There appears to be an outfall at the park's northern edge, which directs water into a paved trench. This water is routed to a stream, adjacent to the BHA complex, which drains to a culvert under the entrance driveway. Several eroded areas and gullies were observed leading to the stream, indicating that the current drainage system is over capacity.

This Drainage Area was subdivided into five subareas for design purposes. This is discussed in the next section.

Town Commons pathways and gazebo, facing north

PROPOSED STORMWATER MANAGEMENT DESIGN

Methodology

To develop the subwatershed stormwater management plan, CRWA developed conceptual designs for selected priority drainage areas and used computer modeling to assess the phosphorus reduction potential of various design scenarios for the entire study area. (Modeling Analysis is discussed in a subsequent section). Nitsch Engineering then developed and sized schematic drawings for each proposed stormwater control.

For the purpose of this study, CRWA's stormwater management control techniques were limited to structural stormwater controls. Operational stormwater controls, such as street sweeping, are not specifically addressed in this plan, although it was assumed that a 15% phosphorous reduction could be achieved in the study area through these mechanisms. From a suite of LID control practices, CRWA identified ten for possible use in the plan (see Table 2). Through the decision and modeling process, these ten were ultimately narrowed down even further to the four most effective, site-responsive and cost efficient solutions:

- Infiltration basin
- Infiltration trench
- Bioretention system
- Rain garden

Stormwater controls were selected, sited and sized, in conjunction with Nitsch Engineering, based on soil conditions (soil profile and water table depth), existing property use, space constraints, stormwater pipe locations and depths, slope, and neighborhood character.

Results

CRWA's conceptual designs for the ten priority sites are outlined in the following section. The optimization section includes information on the remalning sites. Specific practices were selected to meet Town goals, and are based on soil conditions, land use/ownership, existing infrastructure and phosphorus reduction capability.

Stormwater control Type	Infiltrates Runoff	Above Ground Footprint	Aesthetic Value	Depth of Unit (from surrounding land to bottom of unit)	Cost Range ($/cu. ft. water treated)
Bioretention System	No	Yes	High	9 - 36 inches	$$
Rain Garden	Yes	Yes	High	6 - 9 inches	$
Infiltration Basin	Yes	Yes	Low	1 - 4 feet	$
Infiltration Trench	Yes	Yes	Medium	2 - 3 feet	$$
Infiltration Chamber	Yes	No	N/A	N/A	$$$
Dry Extended Detention Basin	No	Yes	Low	> 1 foot	$
Wet Extended Detention Basin	No	Yes	Medium	> 1 foot	$
Gravel Wetland	No	Yes	Medium	> 2 feet	$$
Green Street/Tree filter	No	Yes	High	Varies	$$$
Vegetated Swale	No	Yes	Medium	0.5 - 2 feet	$$

Table 2. Stormwater control cost analysis

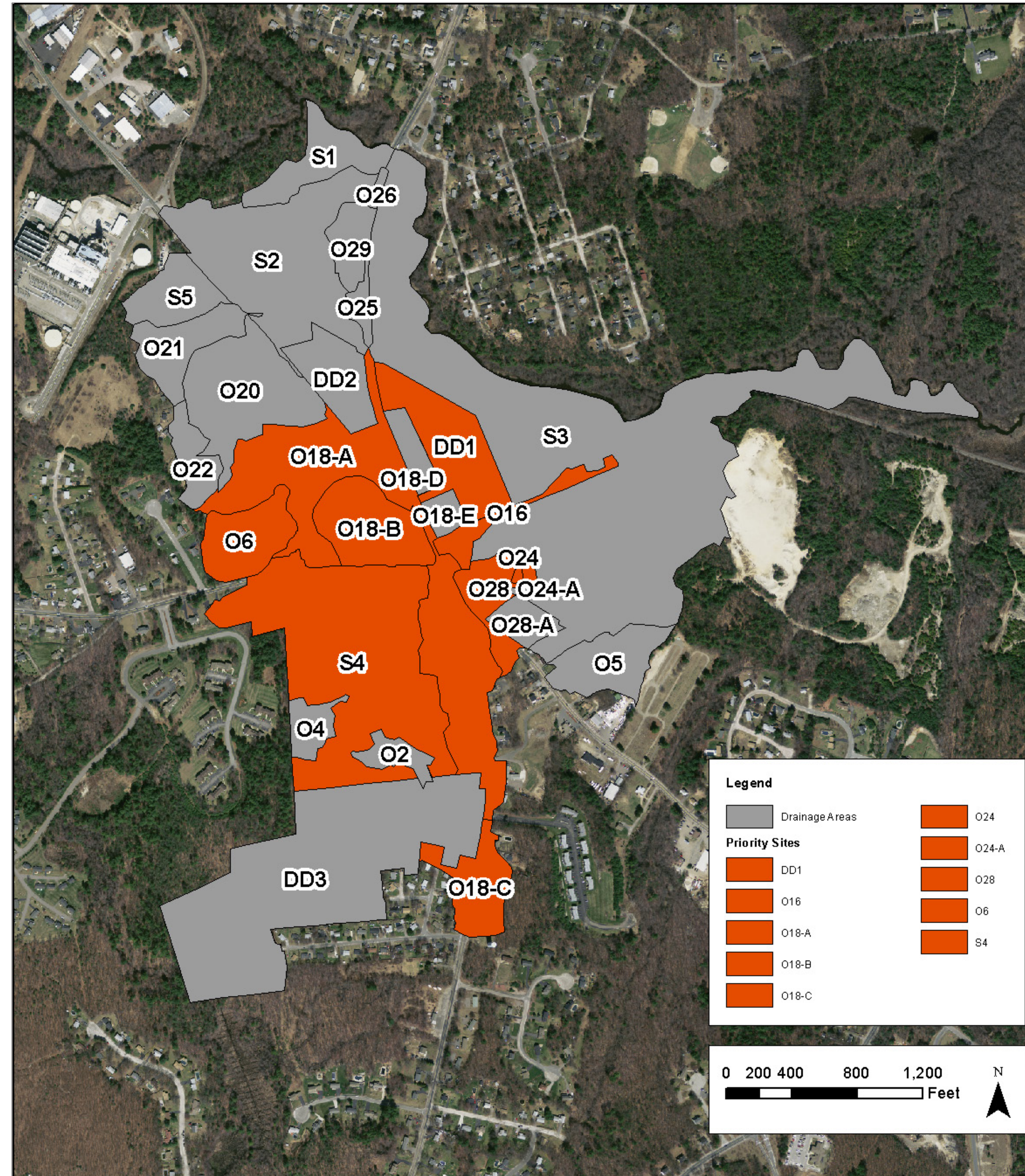
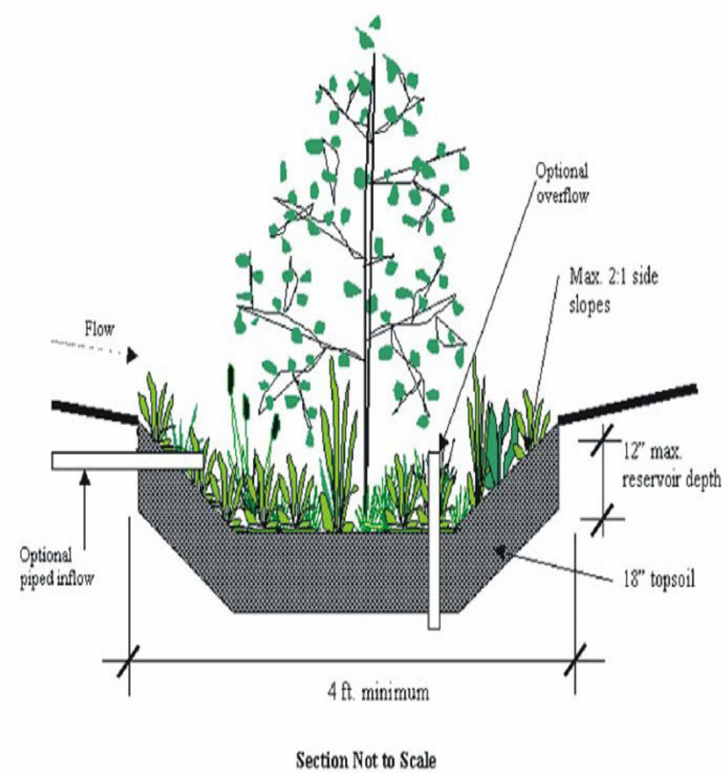


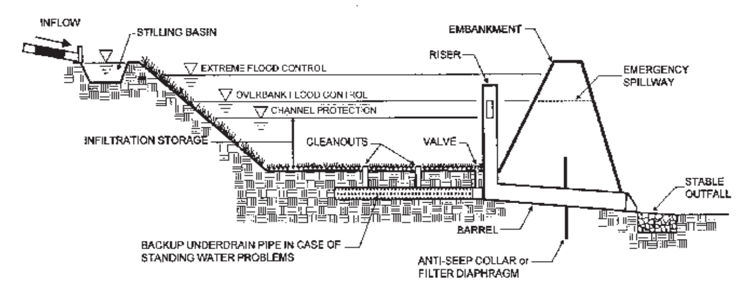
Figure 7. Priority drainage areas in the study area



BIORETENTION

Bioretention systems collect and filter stormwater through layers of mulch, soil and plant root systems where pollutants such as bacteria, nitrogen, phosphorus, heavy metals, oil and grease are retained, degraded and absorbed. Treated stormwater is then infiltrated into the ground or, if infiltration is not appropriate, discharged into a traditional stormwater drain system through under-drains.

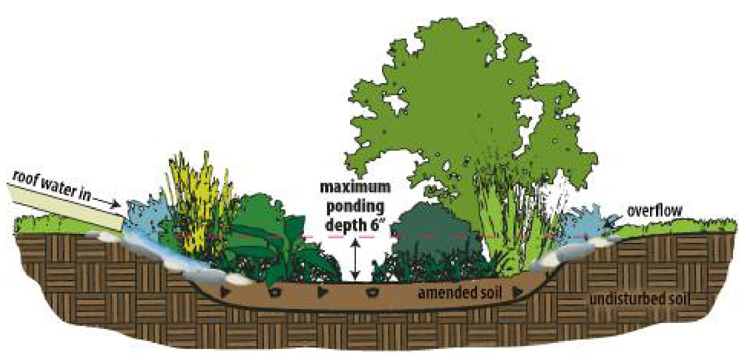
Vegetated bioretention systems have a high aesthetic value, and are an attractive option in developed landscapes.



INFILTRATION BASIN

An infiltration basin is a large depression that is designed to infiltrate stormwater into the soil. Infiltration basins can be quite efficient in removing pollutants, and can also help recharge the groundwater, thus restoring low flows to stream systems.

Because Bellingham has predominantly well-drained soils, infiltration basins are a practical and cost-effective alternative. Infiltration basins are most cost-effective when there is ample space available.

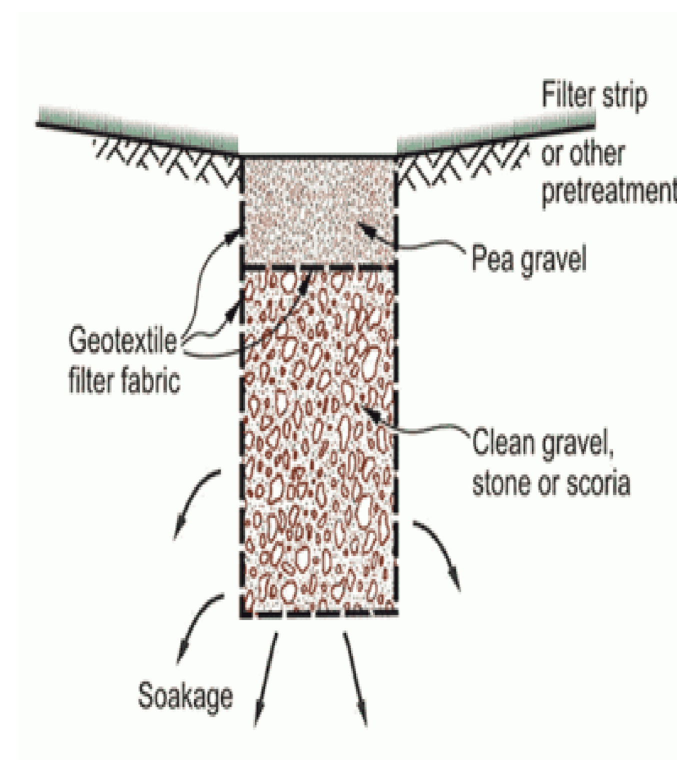


RAIN GARDENS

Rain gardens look similar to traditional gardens, but they differ in design and function. Rain gardens can be planted with a variety of perennials, grasses, shrubs and small trees, with native plants typically preferred. Rain gardens add asthetic value to any site and can be installed at large or small sites.

Rain gardens use shallow detention and infiltration to reduce the volume, flow rate and temperature of stormwater runoff, increase groundwater infiltration and recharge and improve water quality in local surface waterways.

Rain gardens provide a cost effective way of treating stormwater as the ratio of cost to volume of runoff treated is lower than many other stormwater controls.

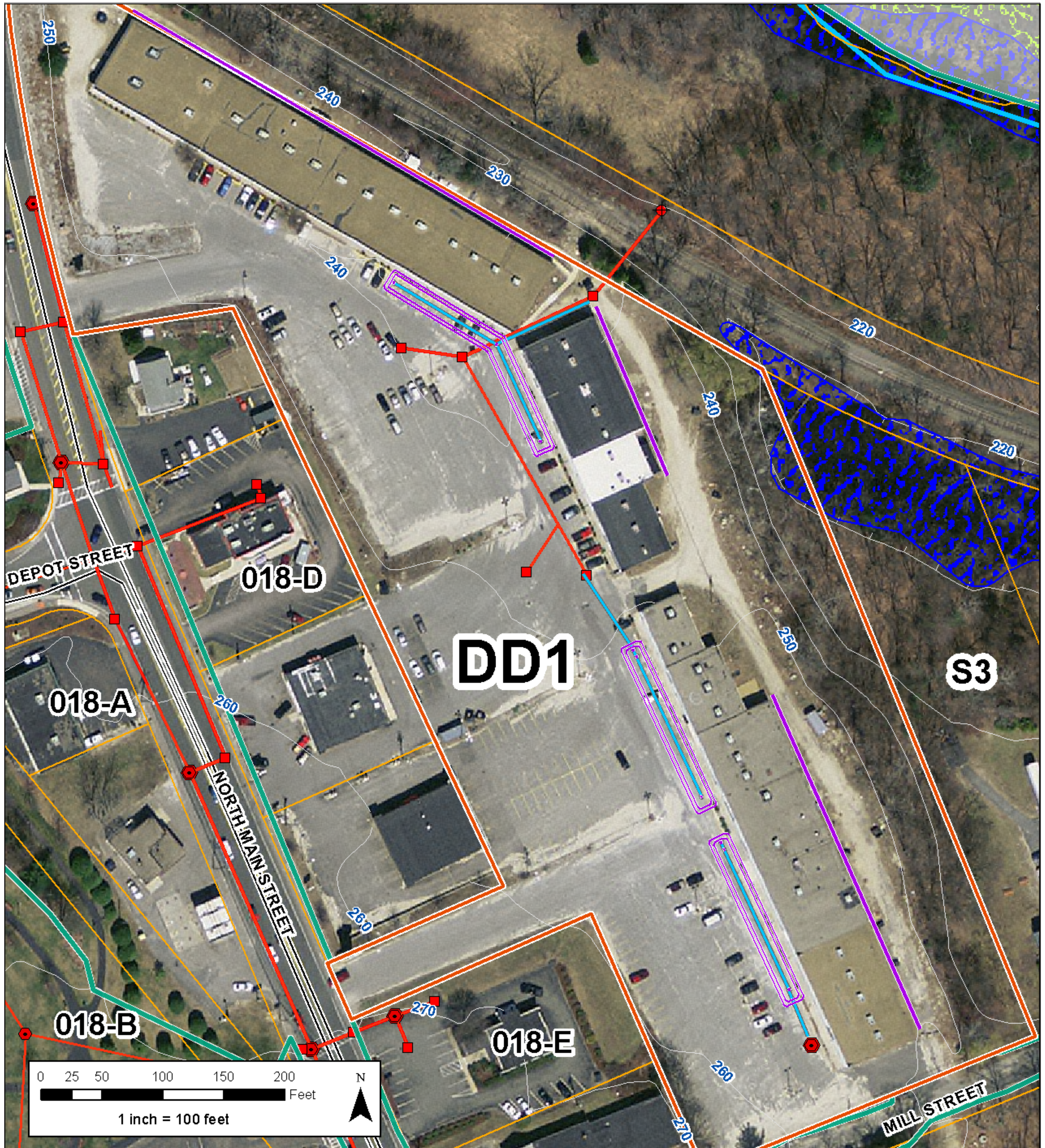


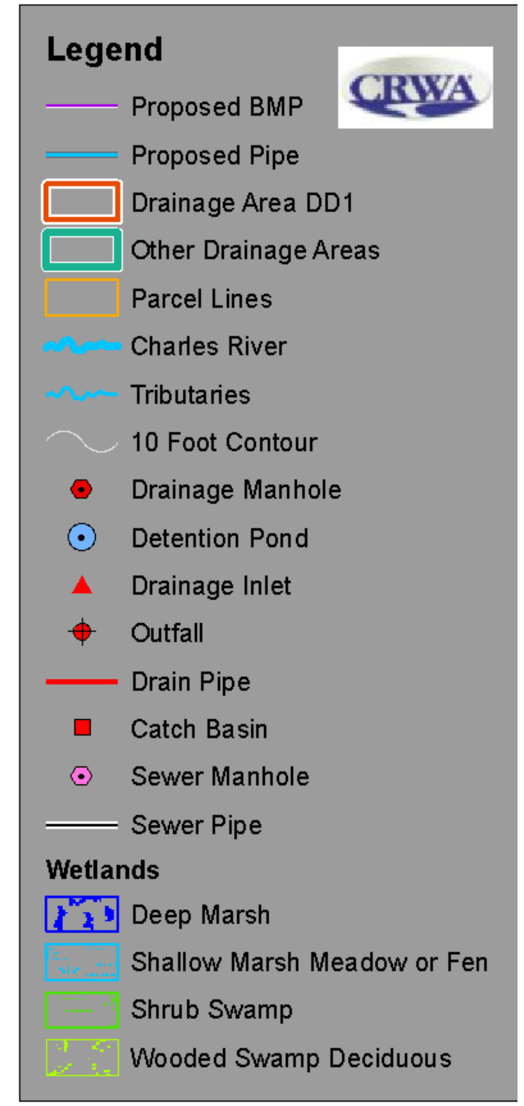
INFILTRATION TRENCH

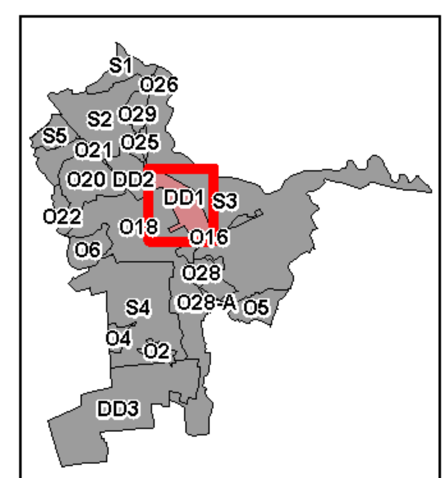
Infiltration trenches are constructed like infiltration basins, but can cost more than infiltration basins and are used predominantly when space is at a premium.

Trench systems capture and infiltrate water through gravel and stone, recharging the groundwater supply.

Infiltration trenches are particularly effective at filtering stormwater and removing heavy metals, phosphorus, nitrogen and bacteria and also have the potential to significantly reduce peak flows and runoff volume.







DD1-B Bellingham Plaza LLC
Stormwater Control Description:

Three infiltration trenches are proposed for the area behind each existing building to capture and treat stormwater runoff from the rooftops. The infiltration trenches are designed to comply with the Mass DEP Stormwater Management Standards which is a requirement for units discharging runoff to the buffer zone of wetland resource areas.[1] During larger storm events, the trenches will overflow to the wetlands located behind the project site which is the current drainage pattern for the site.

1 Standards require treatment and infiltration of up to the 0.5 inch storm event to provide a minimum of 80% total suspended solids removal.

Roof Drainage Area: Infiltration Trenches

Drainage Area (acres)	1.60
Impervious Area (acres)	1.60
Estimated Infiltration Rate (in./hr)	4.46
Target Phosphorus Removal	50.9%
Water Quality Depth (in.)	0.24
Water Quality Volume (ft3)	1,400±
Stormwater Control Surface Area (ft2)	2,250±
Estimated Construction Cost	$7,700

Plan and section details can be found in Appendix C.

BEFORE: Photo of existing end of northwest parking lot

AFTER: Visualization of proposedrain garden

DD1-A Bellingham Plaza LLC
Stormwater Control Description:

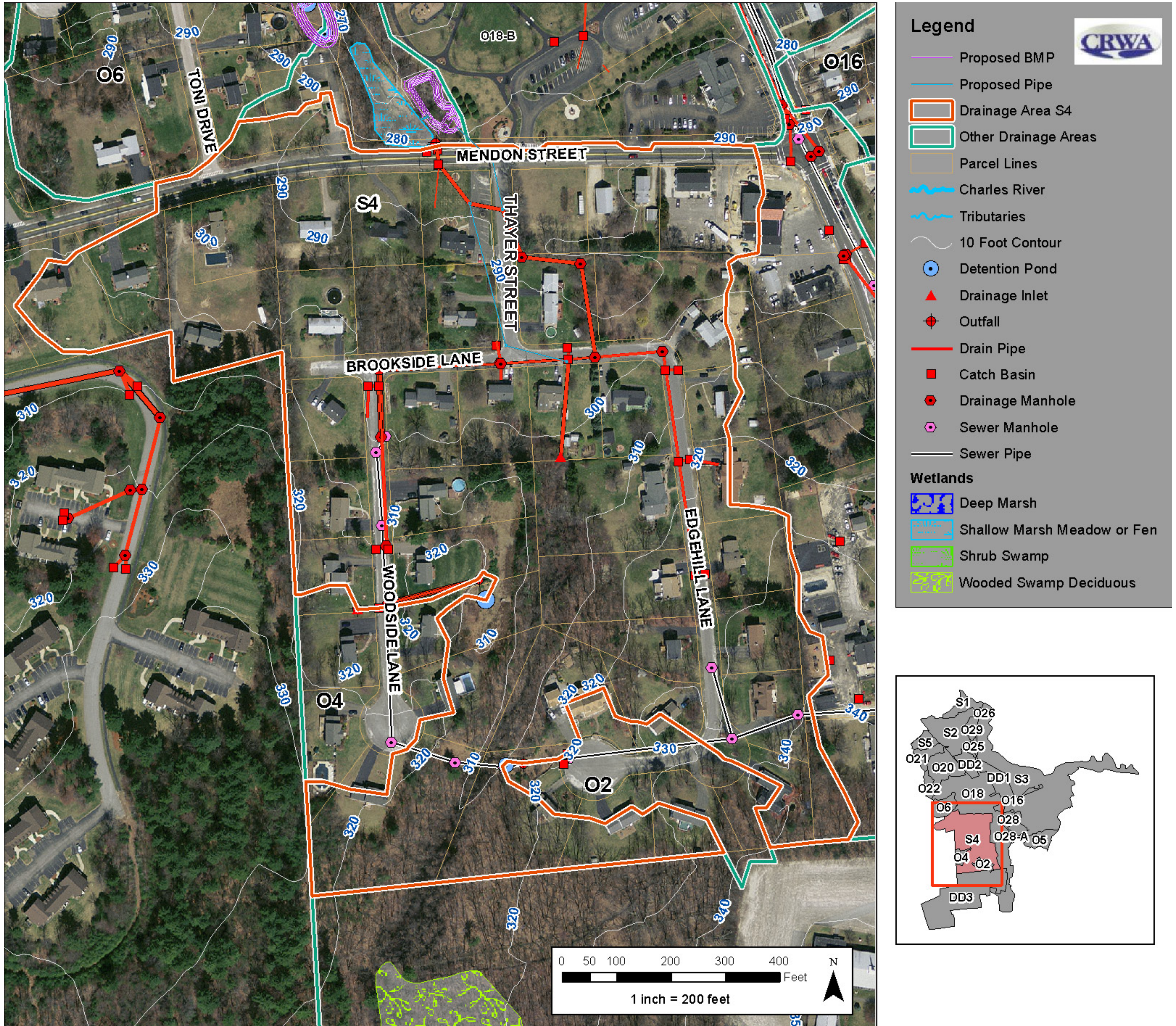
Three rain gardens will capture and treat the stormwater runoff from the existing 4.5-acre parking lot. Runoff will flow from the paved parking lot into a stone-lined forebay, where it will be pre-treated prior to flowing into the rain gardens. An overflow structure is provided in each rain garden to route large storm events into the existing stormwater drainage system. Treated runoff and overflow are discharged into the buffer zone for the wetland area located to the north of the site. The rain gardens are designed to comply with the Mass DEP Stormwater Management Standards, as this is a requirement for units discharging to the buffer zone for the wetland resource areas. [1]

Parking Lot Drainage Area: Rain Gardens

Drainage Area (acres)	4.50
Impervious Area (acres)	4.50
Estimated Infiltration Rate (in./hr)	4.46
Target Phosphorus Removal	50.9%
Water Quality Depth (in.)	0.38
Water Quality Volume (ft3)	6,214±
Stormwater Control Surface Area (ft2)	8,990±
Estimated Construction Cost	$100,300

Plan and section details can be found in Appendix C.

Proposed Designs for Drainage Area S4: Thayer Street/Creek Central

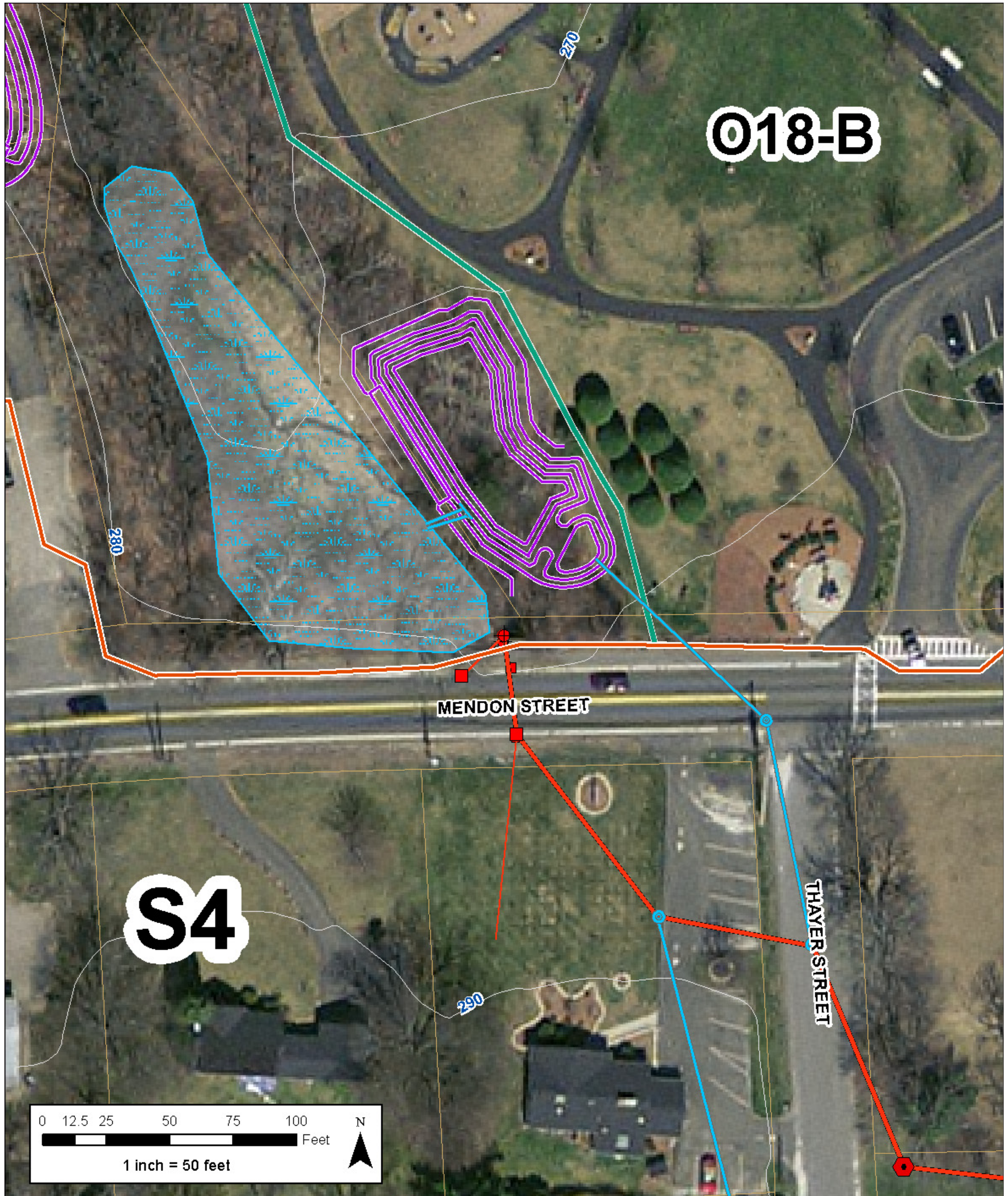


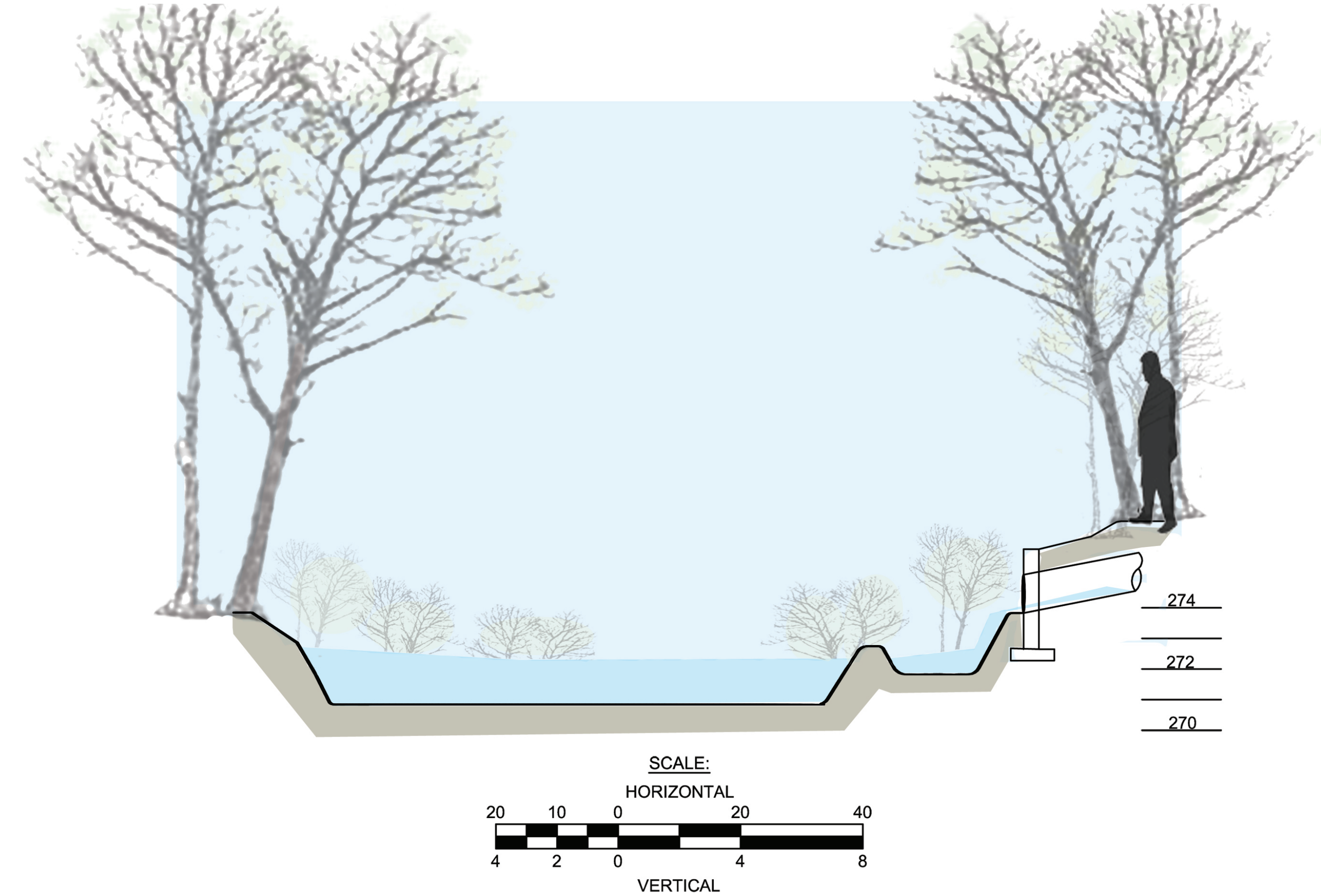
S4 Thayer Street/Creek Central:

Infiltration Basin Stormwater Control Description:

A portion of the intermittent stream flowing through this neighborhood was routed into an enclosed drainage system sometime in the past in order to allow development of housing and roadways. Daylighting of this intermittent stream was deemed unfeasible at this point due to property ownership and liability issues, as well as anticipated costs. Stormwater from this drainage area is collected in existing catch basins and drains located in the roadways, which currently discharge to the same enclosed drainage system that contains the intermittent stream. This stream and the stormwater that discharges into it currently discharge into a wetland located in the town park north of Mendon Street.

Ideally stormwater runoff should be collected and treated prior to mixing with streams. In order to provide a higher level of stormwater treatment than is provided by the current catch basins, the proposed improvements include the separation of the street runoff from the cleaner intermittent stream flow. This is proposed to be done by constructing a bypass pipe to carry stormwater flows to a proposed infiltration basin with sediment forebay, which then overflows to the adjacent wetland and intermittent stream in the town park. Due to the proximity to the wetland, the infiltration basin and sediment forebay have been designed to comply with the DEP Stormwater Management Standards for water quality and will treat and infiltrate up to the 0.5-inch storm event to provide a minimum of 80% total suspended solids removal. Prior to construction of the infiltration basin, the existing wetland will need to be flagged to establish a definite boundary and associated 100-foot buffer zone. Soils testing will also be required within the proposed basin footprint to determine the soil texture, infiltrative capacity, and the elevation of seasonal high groundwater. The infiltration basin may require design adjustments to provide adequate offset to the wetland and groundwater.





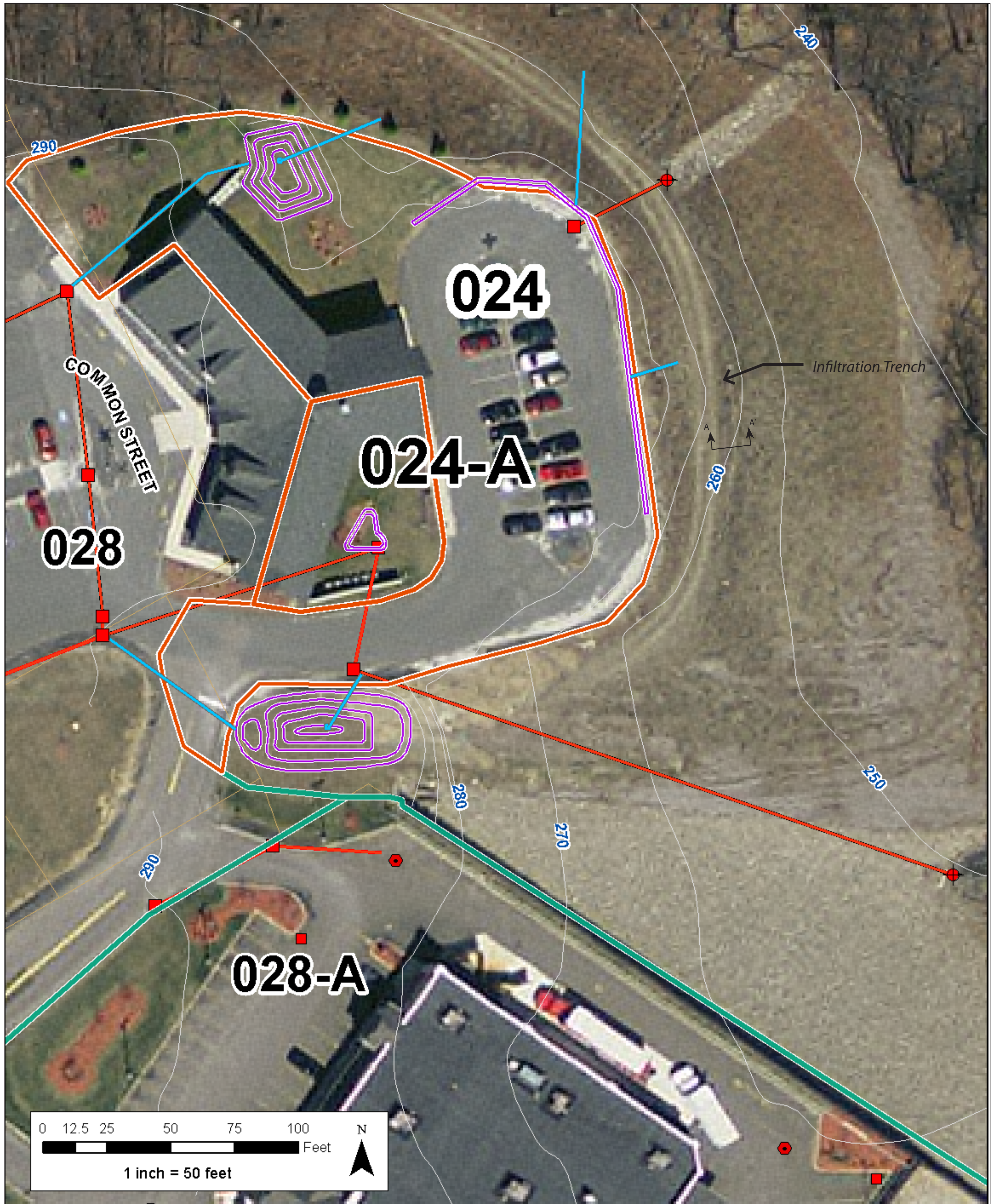
Profile of S4 Infiltration Basin, with exagerated vertical profile to show detail

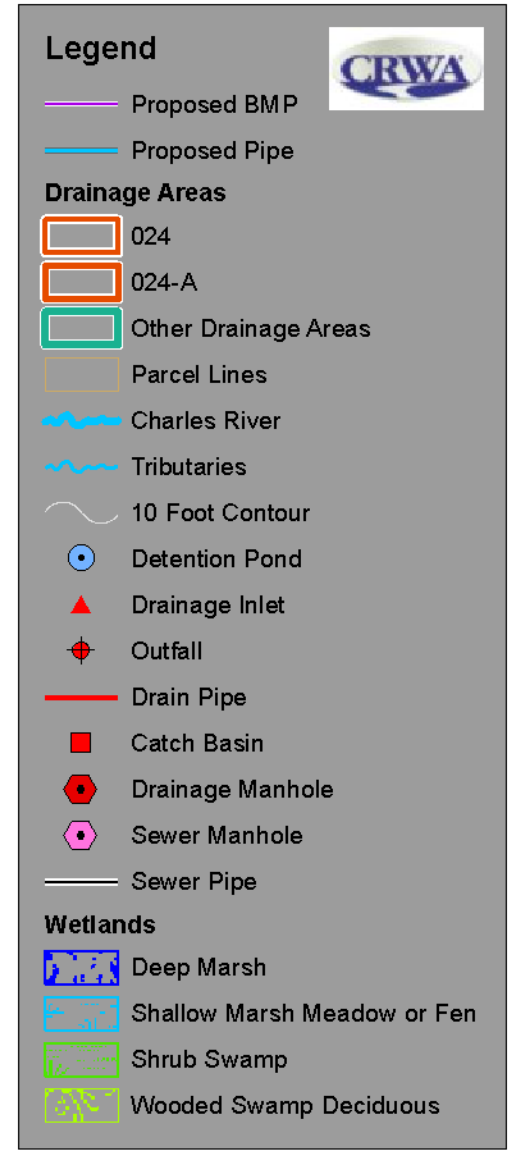
S4 Thayer Street/Creek Central: Infiltration Basin

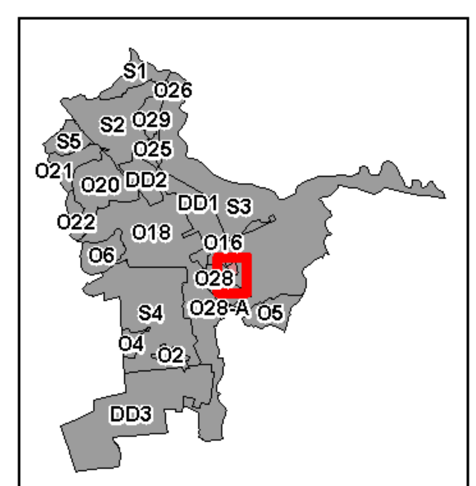
Drainage Area (acres)	26.97
Impervious Area (acres)	5.57
Estimated Infiltration Rate (in./hr)	0.73
Target Phosphorus Removal	64.3%
Water Quality Depth (in.)	0.28
Water Quality Volume (ft3)	5,490±
Stormwater Control Surface Area (ft2)	3,350±
Estimated Construction Cost	$14,800

Plan and section details can be found in Appendix C.

Proposed Designs for Drainage Area O24: Municipal Center







O24 Municipal Center: Infiltration Trench Stormwater Control Description:

An infiltration trench will be constructed to capture, treat, and infiltrate runoff from the driveway and parking lot behind the Municipal center building. Currently, this runoff is all collected by a single catch basin in the rear lot which will remain and act as a bypass of the infiltration trench for larger storm events.

O24 Municipal Center: Infiltration Trench

Drainage Area (acres)	0.68
Impervious Area (acres)	0.68
Estimated Infiltration Rate (in./hr)	4.46
Target Phosphorus Removal	79.5%
Water Quality Depth (in.)	0.48
Water Quality Volume (ft3)	1,130±
Stormwater control Surface Area (ft2)	820±
Estimated Construction Cost	$7,840

Plan and section details can be found in Appendix C.

BEFORE: Photo of existing lawn behind the Municipal Center

AFTER: Visualization of proposed rain garden

O24-A Municipal Center: Rain Garden
Stormwater control Description:

A small rain garden has been designed to capture overland flow from a portion of the Municipal Center roof, driveway, and vegetated lawn area to provide water quality treatment and infiltration. This system will enhance the beauty of this back courtyard area where a small, sparsely planted landscape area is currently sited. Many Municipal Center offices look out onto this courtyard area.

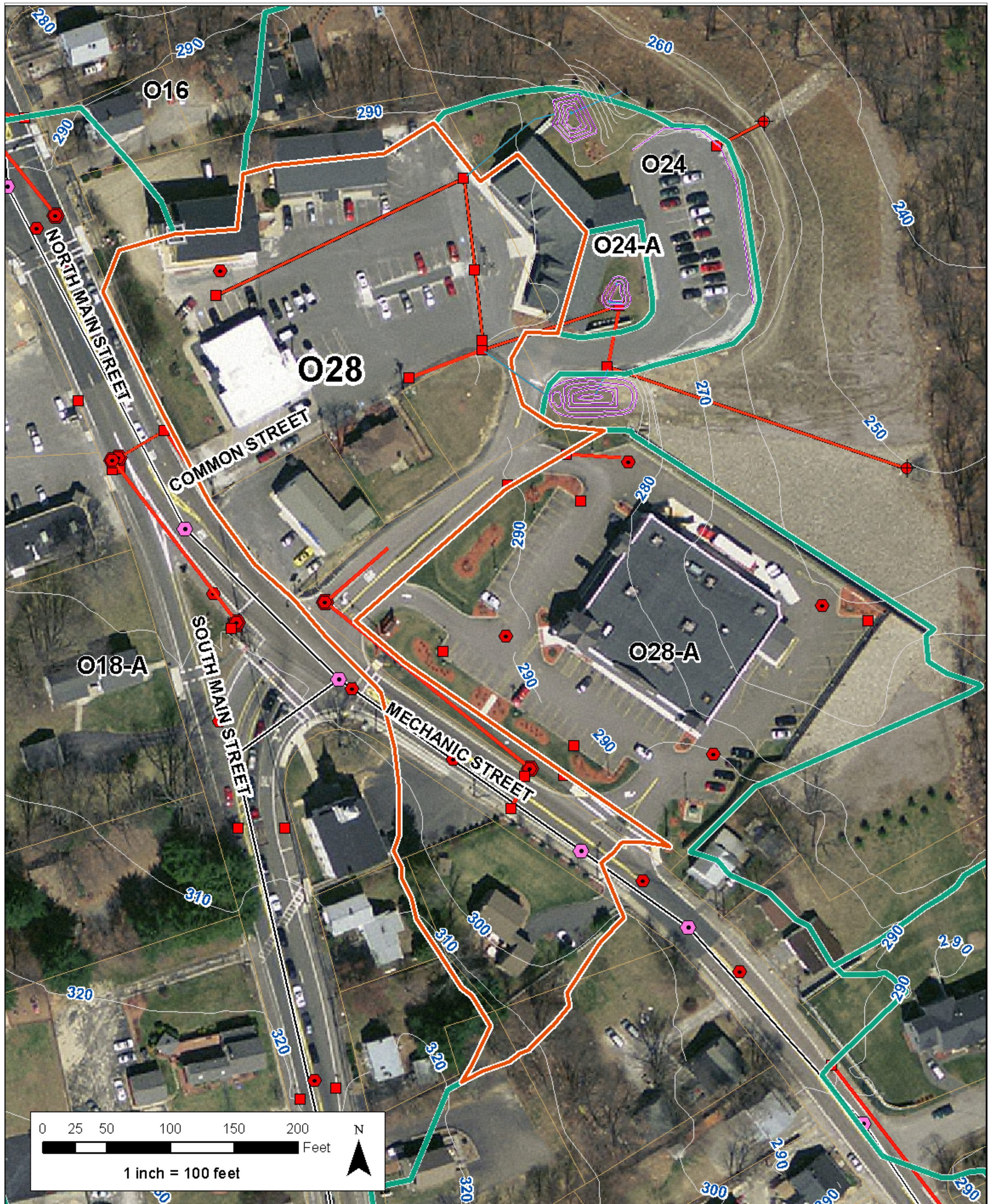
O24-A Municipal Center: Rain Garden

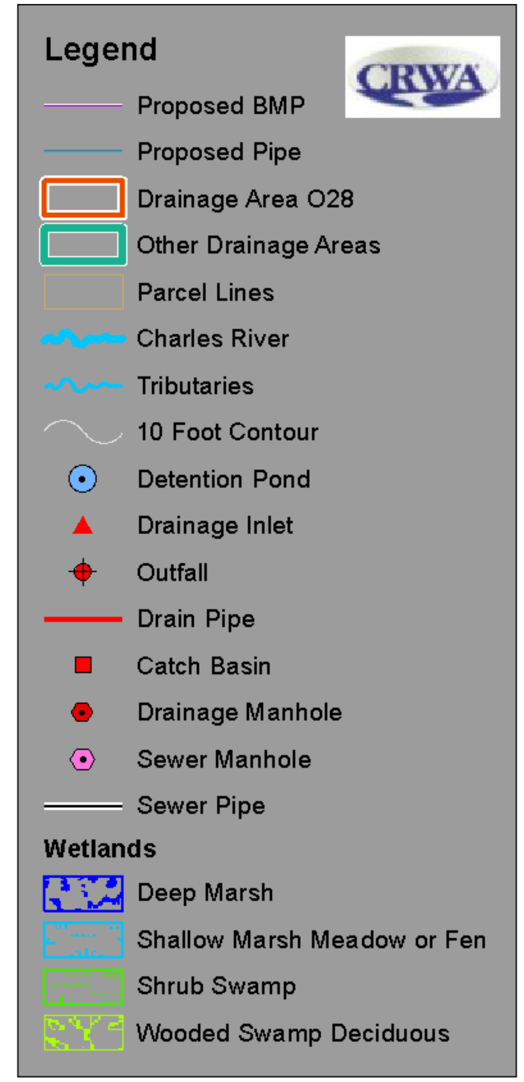
Drainage Area (acres)	0.11
Impervious Area (acres)	0.11
Estimated Infiltration Rate (in./hr)	4.46
Target Phosphorus Removal	85.7%
Water Quality Depth (in.)	0.70
Water Quality Volume (ft3)	280±
Stormwater Control Surface Area (ft2)	420±
Estimated Construction Cost	$1,670

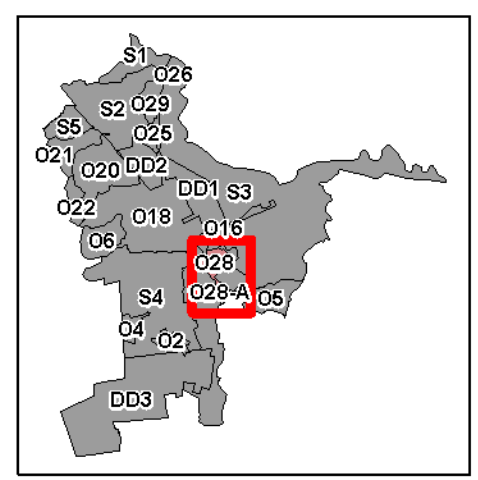
Plan and section details can be found in Appendix C.

"Rain gardens provide a cost effective way of treating stormwater as the ratio of cost to volume of runoff treated is lower than many other stormwater controls."

Proposed Designs for Drainage Area O28: Municipal Center







O28 Municipal Center: Infiltration Basins Stormwater Control Description:

Two infiltration basins with sediment forebays will capture and treat the stormwater runoff from portions of the Municipal Center roof and parking lot. One infiltration basin will be located behind the Municipal Center building on the northeast lawn. The second will be sited to the south of the entrance driveway. Stormwater will be diverted from the underground drainage system at two locations and directed to the infiltration basins for treatment and infiltration.

O28 Municipal Center: Infiltration Basins

Drainage Area (acres)	2.98
Impervious Area (acres)	2.19
Estimated Infiltration Rate (in./hr)	4.46
Target Phosphorus Removal	85.7%
Water Quality Depth (in.)	0.48
Water Quality Volume (ft3)	3,710±
Stormwater Control Surface Area (ft2)	2,680±
Estimated Construction Cost	$12,100±

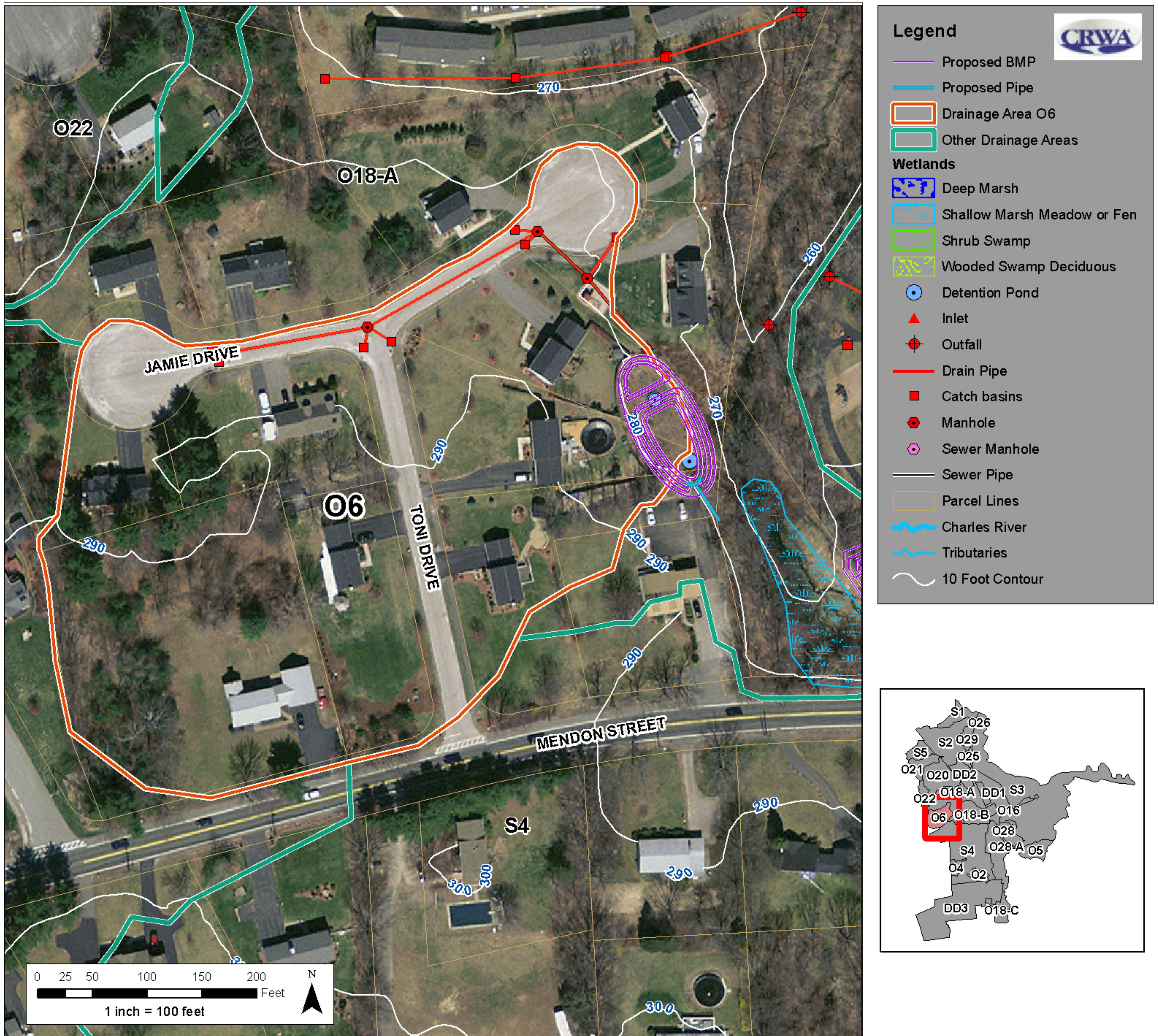
Plan and section details can be found in Appendix C.

BEFORE: Photo of lawn area south of Municipal Center entrance

AFTER: Visualization of proposed basin south of Municipal Center entrance

"Because Bellinghalm has predominantly well-drained soils, infiltration basins are a practical and cost-effective alternative."

Proposed Designs for Drainage Area O6: Toni and Jamie Drive Cul-de-Sac



O6 Toni and Jamie Drive: Detention Pond Retrofit to Infiltration Basin Stormwater Control Description:

The existing detention pond located in this drainage area is currently overgrown with invasive species and it is unclear if the basin is functioning as designed. To provide additional water quality treatment and infiltration, the pond will be converted into an infiltration basin with a sediment forebay. The existing outlet structure will be used to discharge overflow from the infiltration basin. The infiltration basin has been designed to comply with the Mass DEP Stormwater Management Standards because it may be located within the buffer zone to adjacent wetland resources.

O6 Toni and Jamie Drive: Basin Retrofit

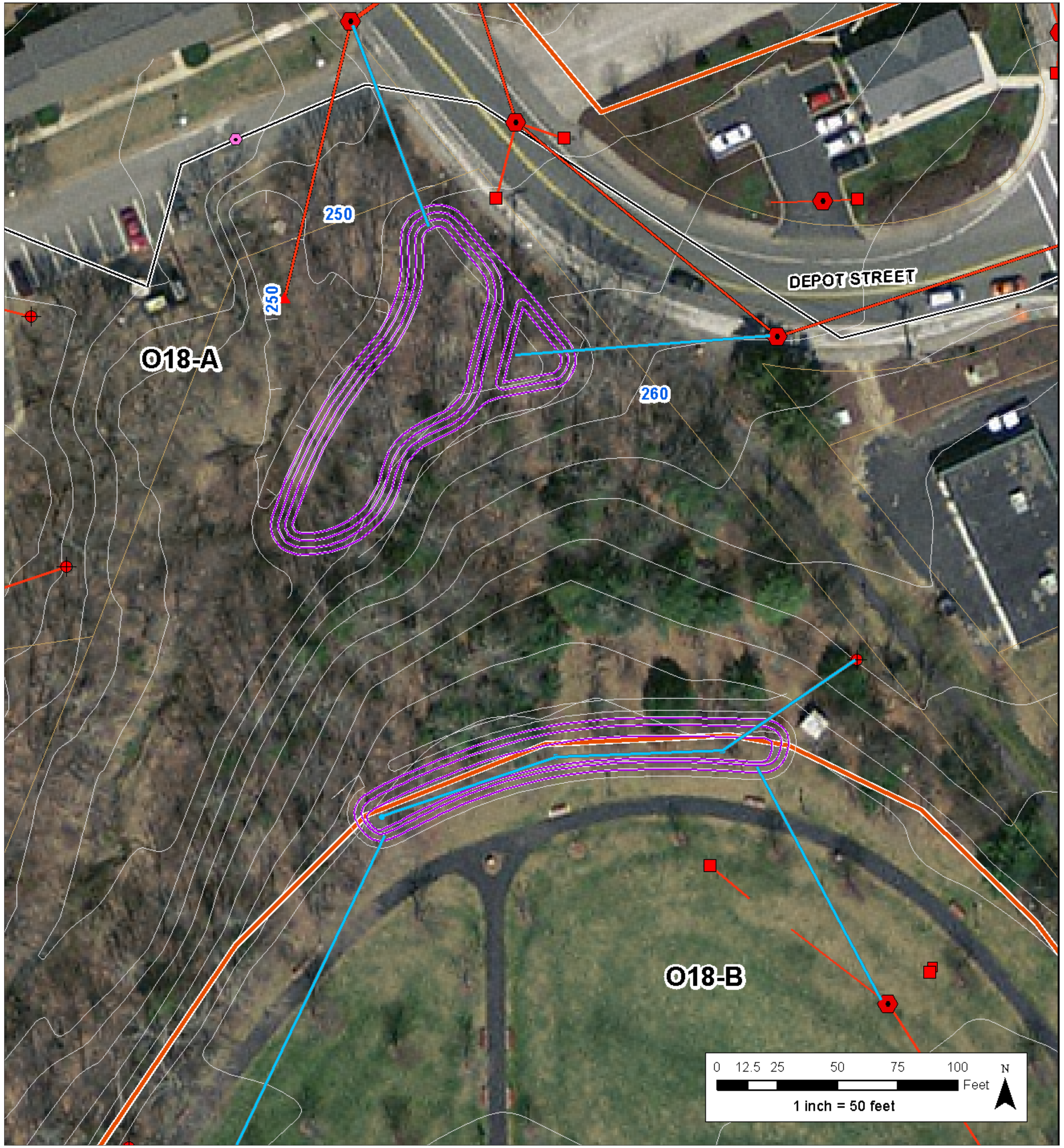
Drainage Area (acres)	4.92
Impervious Area (acres)	1.15
Estimated Infiltration Rate (in./hr)	0.61
Target Phosphorus Removal	85.1%
Water Quality Depth (in.)	0.61
Water Quality Volume (ft3)	2,670±
Stormwater Control Surface Area (ft2)	7,170±
Estimated Construction Cost	$14,870

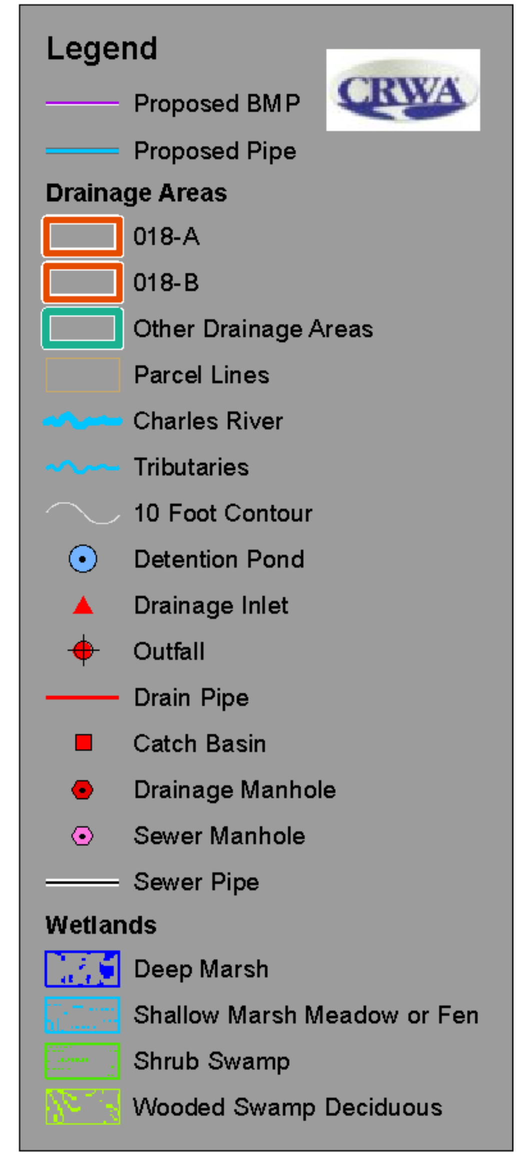
Plan and section details can be found in Appendix C.

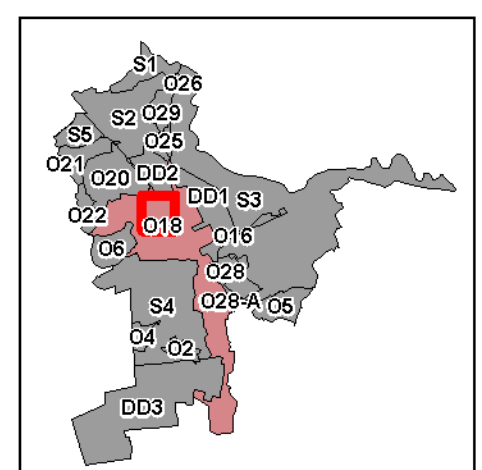
BEFORE: Photo of existing detention basin

AFTER: Visualization of proposed infiltration basin retrofit

"The existing detention pond located in this drainage area is currently overgrown with invasive species and it is unclear if the basin is functioning as designed . To provide additional water quality treatment and infiltration, the pond will be converted into an infiltration basin with a sediment forebay"







O18-A North Main Street: Infiltration Basin Stormwater Control Description:

An infiltration basin and sediment forebay will capture, treat, and infiltrate the runoff from a large portion of North Main Street and the surrounding developed area. A bypass weir will be constructed in the existing drainage manhole located on the south side of Depot Street. The bypass weir will direct runoff from smaller storms into the basin but keep runoff from larger storms in the existing stormwater drainage pipes. The closed drainage system for the development located west of the proposed basin discharges upstream of the basin. This runoff will flow overland into the basin for treatment and infiltration .

O18-A North Main Street: Infiltration Basin

Drainage Area (acres)	23.51
Impervious Area (acres)	9.49
Estimated Infiltration Rate (in./hr)	0.73
Target Phosphorus Removal	73.5%
Water Quality Depth (in.)	0.36
Water Quality Volume (ft3)	12,450±
Stormwater Control Surface Area (ft2)	7,960±
Estimated Construction Cost	$23,700

Plan and section details can be found in Appendix C.

BEFORE: Photo of north edge of Town Commons

AFTER: Visualization of proposed bioretention basin

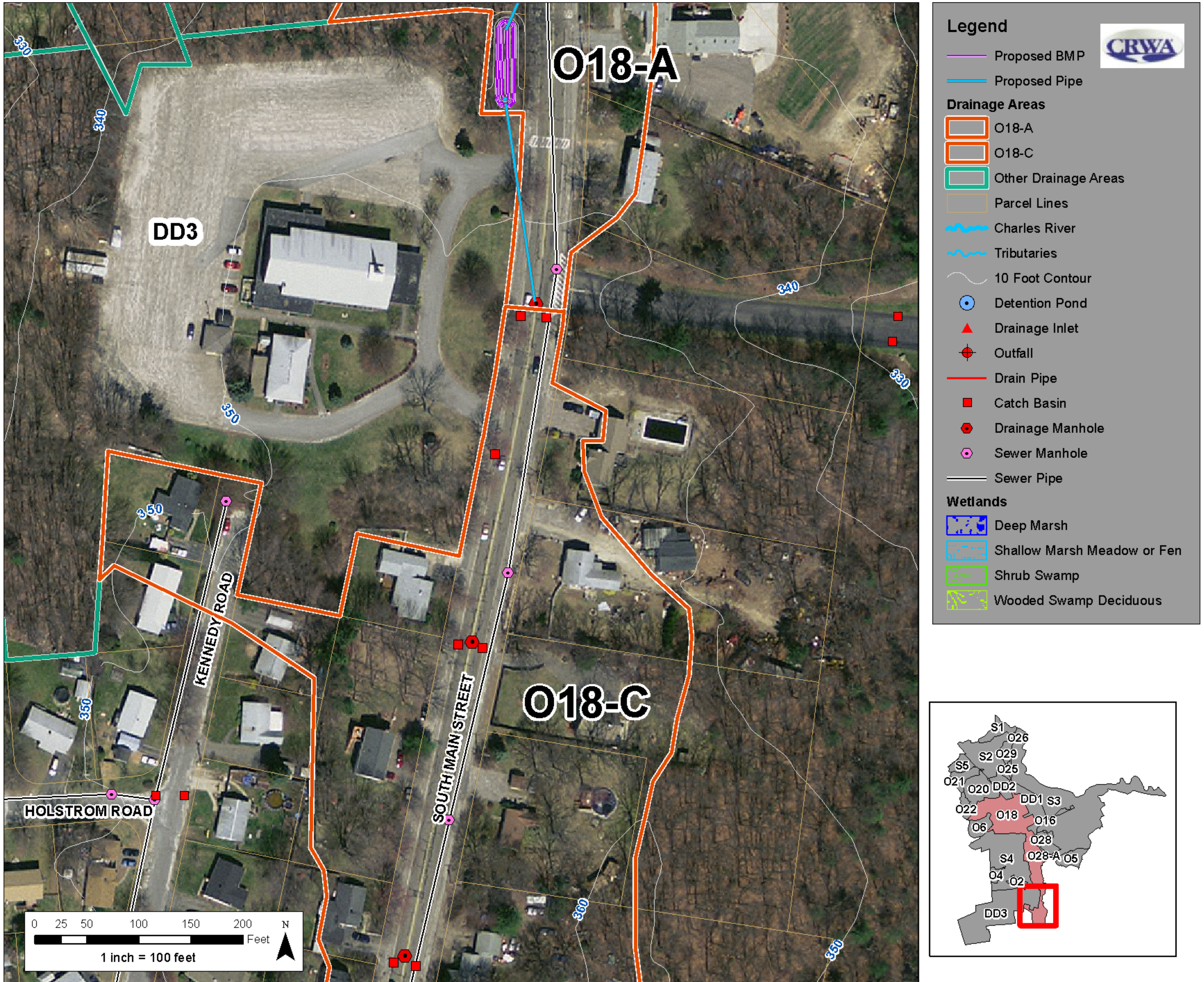
O18-B Town Park on North Main Street: Rain Garden Stormwater Control Description:

A rain garden will provide treatment for the existing park and associated parking lot and walking trails. Runoff generated by the development located southeast of the park will also be captured and treated in the bioretention basin. An overflow structure is provided in the rain garden to re-route large storm events around the unit.

O18-B North Main Street: Rain Garden

Drainage Area (acres)	6.52
Impervious Area (acres)	2.34
Estimated Infiltration Rate (in./hr)	0.73
Target Phosphorus Removal	58.1%
Water Quality Depth (in.)	0.23
Water Quality Volume (ft3)	2,000±
Stormwater Control Surface Area (ft2)	3,840±
Estimated Construction Cost	$25,400

Plan and section details can be found in Appendix C.



O18-C South Main Street: Bioretention System Stormwater Control Description:

A bioretention system will be located on a small town parcel adjacent to South Main Street to provide water quality treatment for small storm events, treating runoff from a 700 foot section of South Main Street and the surrounding developed area. A bypass weir will be constructed in an existing drainage manhole near the intersection of South Mains St. and Crystal Way, the bypass weir will divert the runoff from smaller storms into the system and bypass the runoff from larger storms. The soils in this area are not suitable for infiltration, therefore an underdrain within the system will collect the treated stormwater and discharge it back to the underground drainage system on South Main Street.

O18-C North Main Street: Bioretention System

Drainage Area (acres)	4.49
Impervious Area (acres)	1.45
Estimated Infiltration Rate (in./hr)	0.21
Target Phosphorus Removal	34.0%
Water Quality Depth (in.)	0.20
Water Quality Volume (ft3)	1,090±
Stormwater Control Surface Area (ft2)	±1,410±
Estimated Construction Cost	$20,000

Plan and section details can be found in Appendix C.

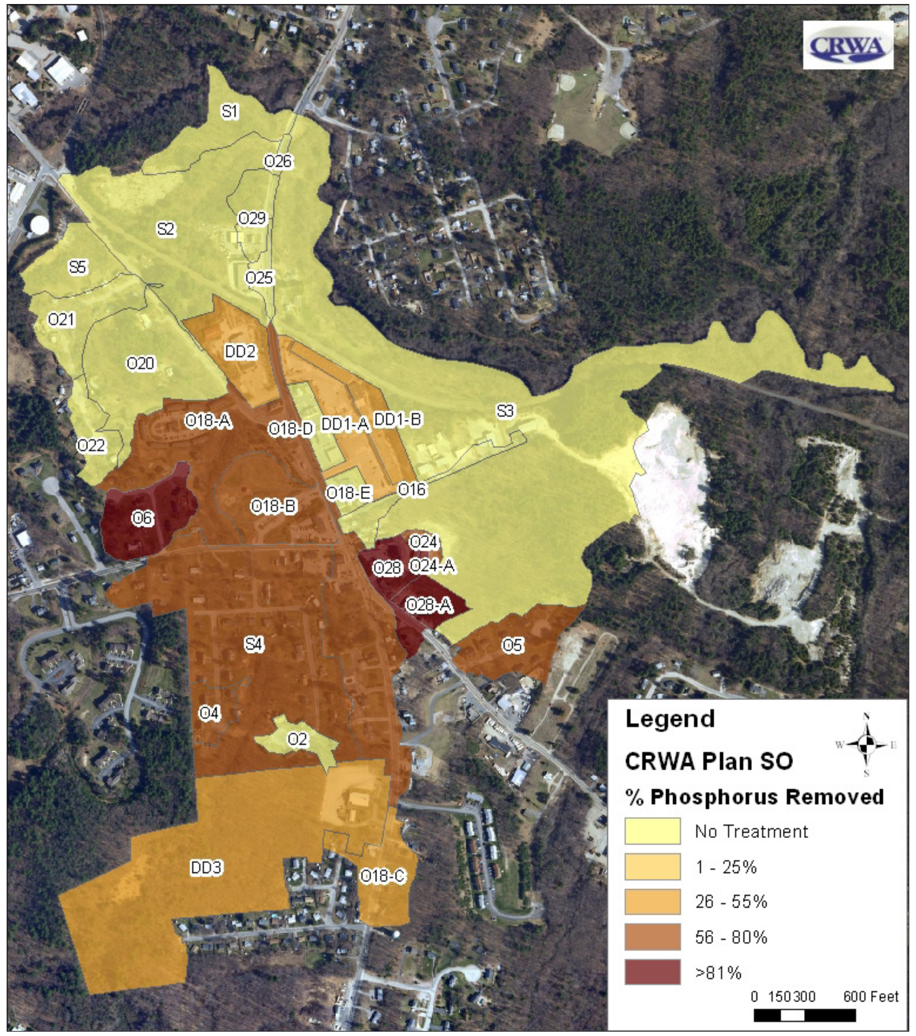


Figure 8. Phosphorous reduction modeling scenario 0

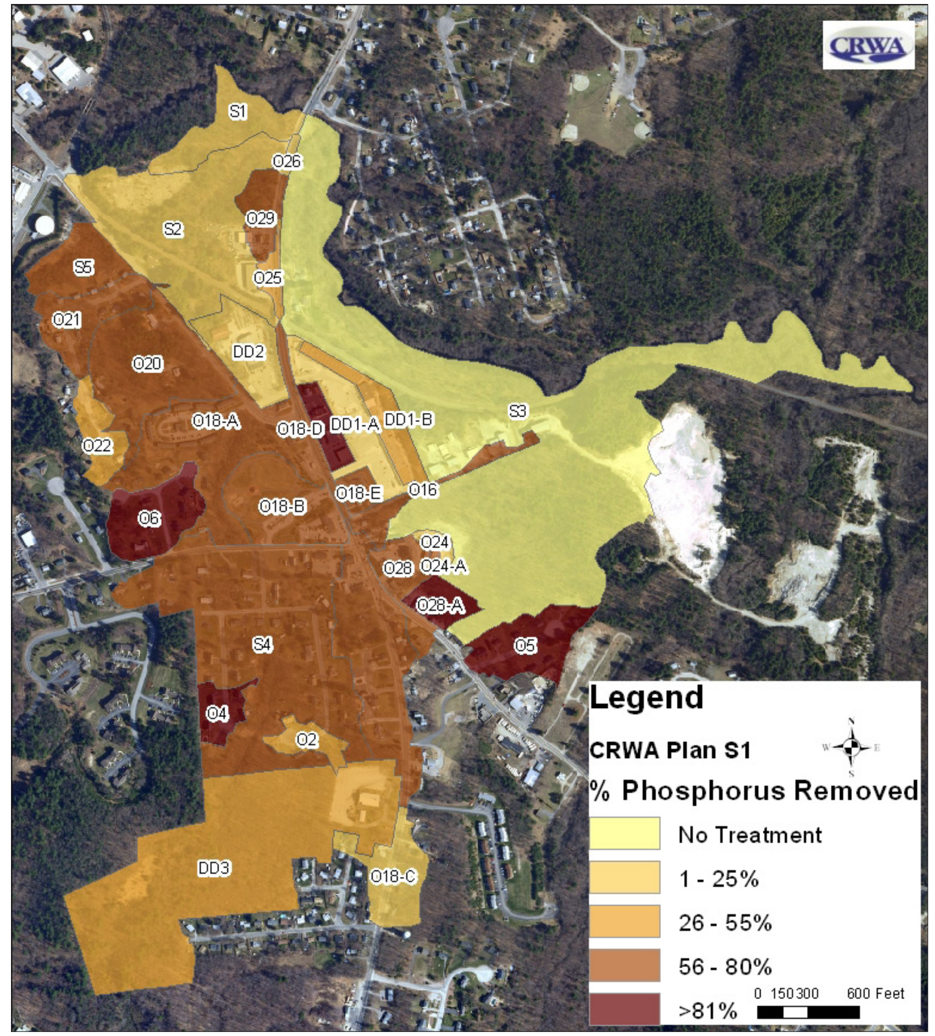


Figure 9. Phosphorous reduction modeling scenario 1

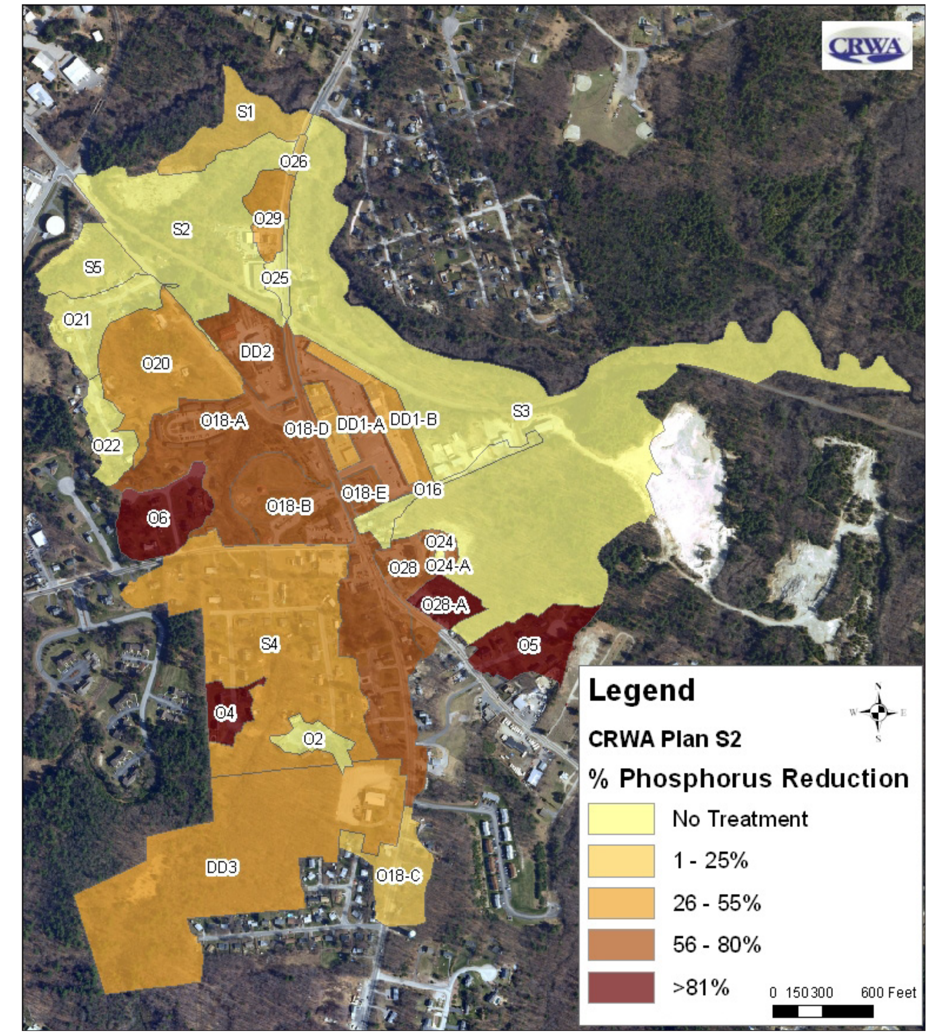


Figure 10. Phosphorous reduction modeling scenario 2

Modeling Analysis:

The study area was divided into 29 small Drainage Areas based on topography , stormwater infrastructure, and property boundaries. While only a subset of ten of those drainage areas were selected as priority sites for stormwater controls, schematic designs were produced for all areas and were incorporated into the model to develop a stormwater management plan to achieve the target net reduction of 41% for the study area.

CRWA used a relatively simple spreadsheet model, performing all the basic calculation in Microsoft Excel. The eVolver optimization tool was incorporated into the spreadsheet model to minimize costs while still meeting the net phosphorus reduction target of 41%. Treatment options were limited to structural stormwater controls and only a subset of ten possible stormwater controls were considered (See Table 2. page 16).

The existing phosphorus load in stormwater runoff was calculated for each of the 29 drainage areas using drainage area land use (MassGIS Land Use, 2005) and the updated phosphorus loading rates for each land use developed by TetraTech (2009). Phosphorus removal efficiencies were modeled based on removal curves developed by long-term modeling of stormwater controls (TetraTech, 2010) using data collected at the University of New Hampshire's Stormwater Treatment and Evaluation Center (UNHSC, 2007). Removal efficiencies are based on the volume of water treated by the stormwater control. The removal efficiency of the proposed system multiplied by the existing load gives the phosphorus load reduction for each Drainage Area. The reductions for each individual Drainage Area must total 41% for the overall study area.

Three sites within the study area have more than two acres of connected impervious cover and have been identified as being subject to EPA's new draft designated discharge (DD) stormwater permit (US-EPA, 2010). These properties (DD1, DD2 and DD3) were each defined as separate drainage areas. One site, 028-A, has an existing underground infiltration chamber, phosphorous reduction was calculated for this existing system and included in the model.

In the model, construction cost for each stormwater control was estimated using unit cost coefficients of dollar per cubic foot treated (See Table 5., Appendix B) for relative costs) and the runoff volume treated by each stormwater system. The volume of water treated is the stormwater control volume plus an allowance for percolation for infiltration systems.

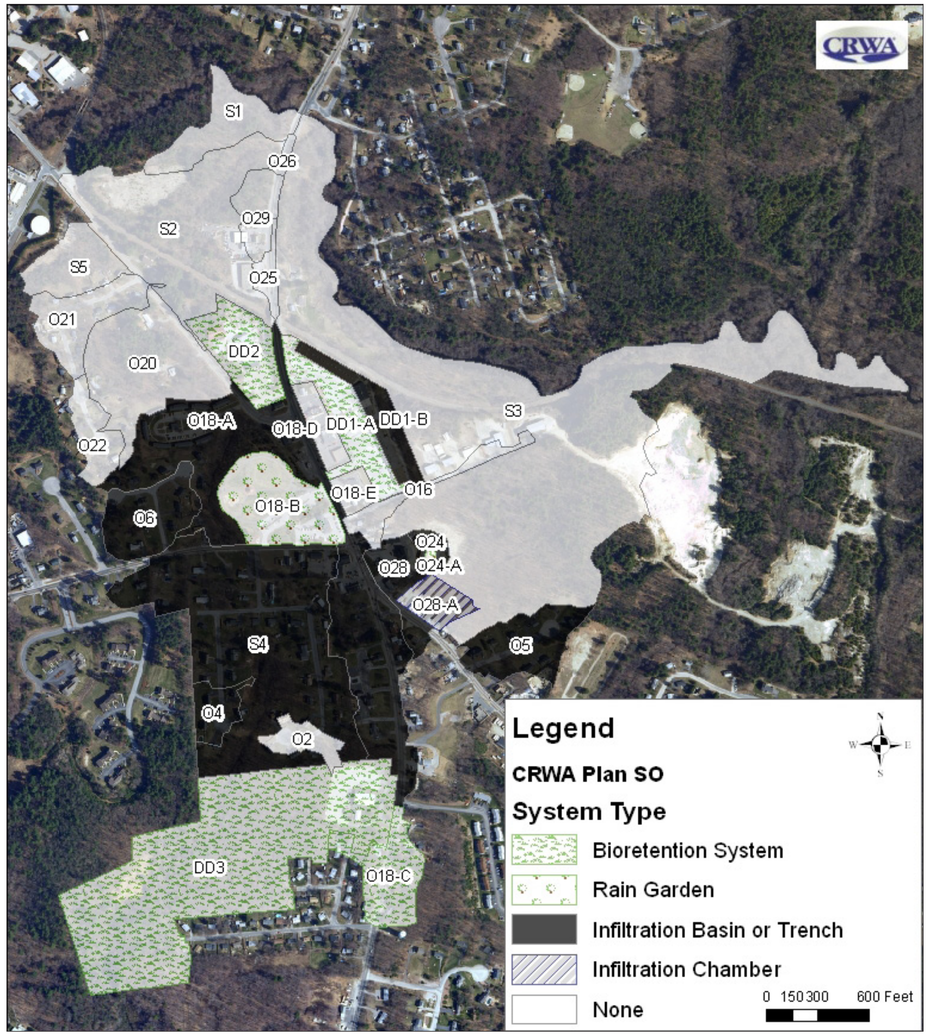


Figure 11. Systems used in scenario 0

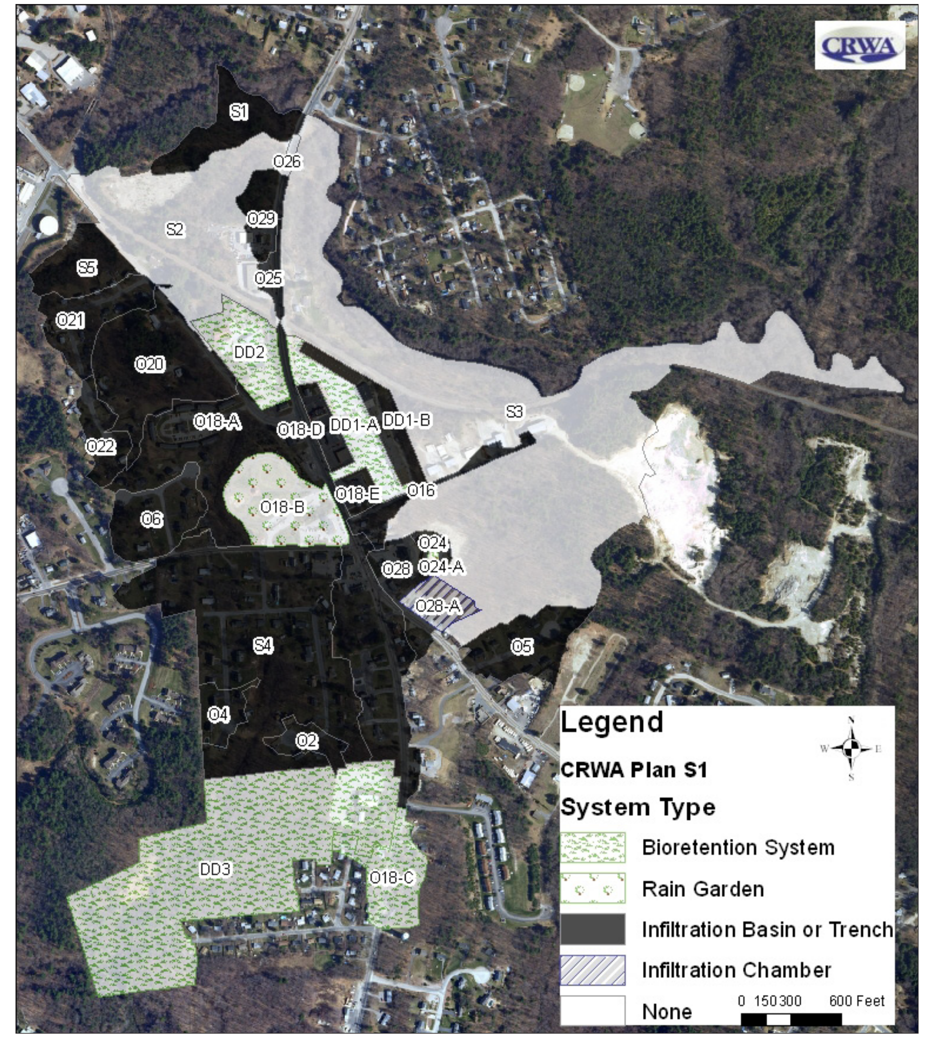


Figure 12. Systems used in scenario 1

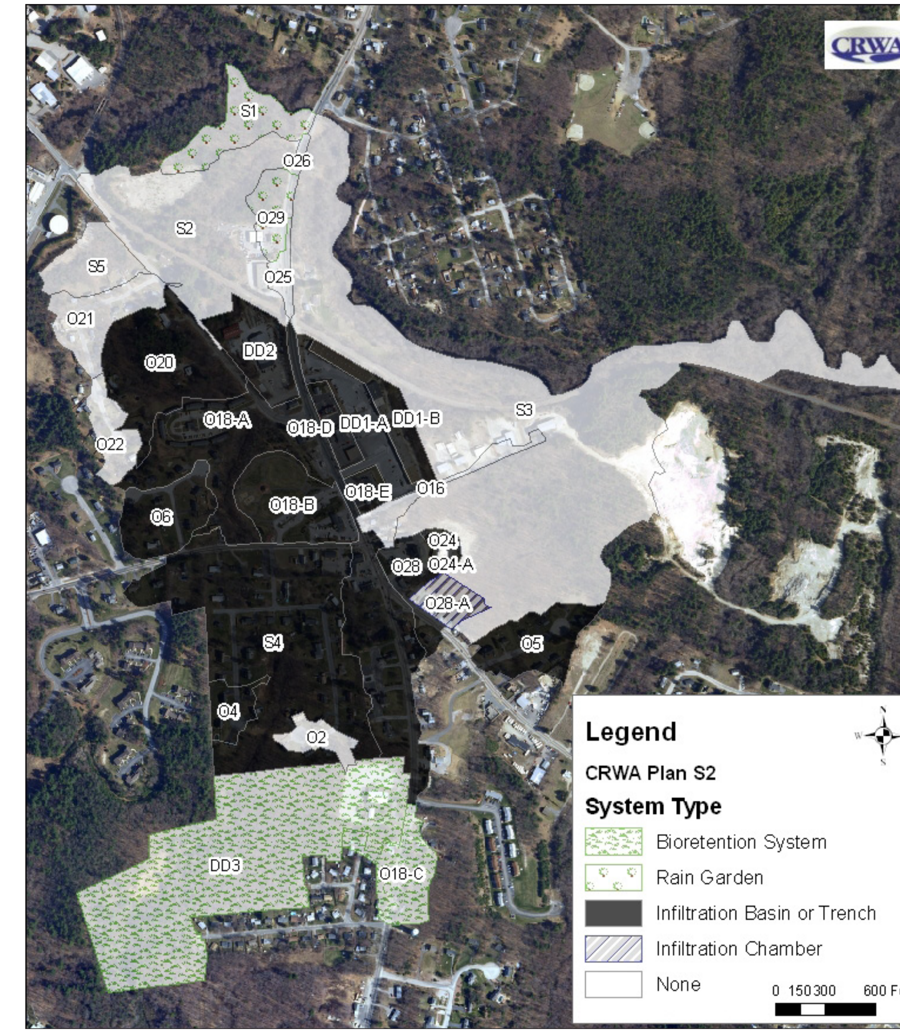


Figure 13. Systems used in scenario 2

CRWA developed three modeling scenarios which are discussed in detail below. Scenario 0 is the base scenario, stormwater controls were chosen by best professional judgment. Scenarios 1 and 2 are optimized scenarios; optimization was done using the eVolver optimizer, a genetic algorithm for Excel, to minimize the total construction costs by varying individual stormwater control unit design volume (Scenario 1) or design volume and control type (Scenario 2) with the constraint that the target net phosphorus reduction of 41% must be equaled or exceeded. Optimization yields least-cost scenarios using different stormwater control sizes and/or types while still meeting the target phosphorus reduction.

Stormwater Management Plan Results

CRWA developed three retrofit plans. Preliminary cost estimates for the stormwater management plan for the study area range from approximately $200,000 to nearly $500,000. Results of the three scenarios are presented below.

Scenario 0: Initial Design Plan

CRWA selected sites and stormwater controls based on a thorough review of existing drainage, stormwater infrastructure, available land, mapped soil conditions, slopes, desired pollutant removal efficiencies, sizing constraints, discussions with Town officials, consultations with engineering professionals at Nitsch Engineering, and estimated cost. In this scenario, the target reduction for each Designated Discharge site was set at 51% because EPA has stated that these sites will be required to reduce phosphorus in runoff by 65%; and CRWA assumed property owners would achieve 14% of these reductions through non-structural mechanisms. Drainage area S3 had no proposed treatment unit as this area does not have a defined outlet location where a stormwater control could be placed; therefore the reduction for this area was set at 0. Site 028-A was also fixed, at 41% because it has an existing, functioning system which CRWA determined achieves that phosphorus removal rate. The remaining drainage areas did not have set individual target reductions; reductions were calculated based on the type and size of system appropriate given existing site conditions. The overall plan was developed such that cumulatively, reductions for all Drainage Areas met the study area target of 41% net reduction in the phosphorus load in stormwater runoff.

Scenario	Drainage Areas with No Treatment (#)	Drainage Areas with 1 – 50% Treatment (#)	Drainage Areas with 51 – 89% Treatment (#)	Drainage Areas with > 90% Treatment (#)
S0	14	2	13	0
S1	3	10	13	3
S2	9	5	13	2

Table 3

The designed retrofit plan results in a 41% reduction at a cost of $467,715. Appendix A summarizes the complete results of this plan and detailed designs for the ten priority sites are shown in the previous section.

Scenario 1: Stormwater Control Design Size Optimization

Scenario 1 was created through a model optimization set to minimize costs while meeting the target for total phosphorus removal. The optimization varied the stormwater control volume for the stormwater controls in each Drainage Area and looked for the optimal combination of stormwater control treatments to minimize costs. No upper or lower bounds were set on stormwater control treatment volumes, however, resultant control unit sizes are checked at the end of a model run to make sure they will fit on a particular site. In general, the optimization runs spread reductions over more stormwater controls so they are usually smaller not bigger than the initial size. In this Scenario and in Scenario 2 no fixed target reduction was set for the DD sites, as it was in Scenario 0 . Type of stormwater control and location for each drainage area, however, were fixed during the optimization run in accordance with Scenario 0. Site 028-A was again fixed at 41% in both optimization runs.

The optimized scenario results in a 41% reduction in the phosphorus load in stormwater runoff at a cost of $264,750. Since Scenario 1 is the result of a numeric optimization it does not account for some factors that would affect feasibility of implementation in the real world such as public opinion, neighborhood character, and site aesthetics. Complete results for this plan are presented in Appendix A.

Scenario 2: Stormwater Control Type and Design Size Optimization Results

Scenario 2 is also a model optimization. This scenario differed from Scenario 1 in that stormwater control types were not fixed. For each Drainage Area, CRWA determined which stormwater controls were physically feasible on the site given space constraints, slopes, and mapped soil conditions. The optimization model selected the preferred stormwater control for each Drainage Area from the suite of allowable stormwater controls for that Drainage Area. The model also varied the stormwater control design storm depth to determine the best overall treatment plan. Scenario 2 meets the target net reduction of 41% at a cost of $212,540. Scenario 2 is also the result of a numeric optimization that does not take into account some factors that would affect feasibility of implementation in a real world scenario such as public opinion, neighborhood character, and site layout and aesthetics. Complete results for this plan are presented in Appendix A.

Discussion

The model optimization results (S1 and S2) both had fewer drainage areas receiving no stormwater runoff treatment when compared to the initial stormwater management plan (S0). Scenario 0 has 14 drainage areas receiving no treatment versus only 3 in Scenario 1, and 9 in Scenario 2 (Table 3 and Figures 8, 9 and 10). Scenario 1 includes more systems treating smaller water volumes from more Drainage Areas. Since most stormwater controls deployed in this plan have a smaller treatment volume, they fall on a steeper part of the removal efficiency curve. By employing multiple stormwater controls, each treating small water quality volumes, the result is greater aggregate phosphorus removal across the study area at a similar overall treatment volume, and a reduced cost. This result is also consistent with the general principals of LID in which smaller, onsite systems are encouraged.

Drainage Area	S0	S1	S2
DD1-A	51%	5%	59%
DD1-B	51%	35%	51%
DD2	51%	4%	64%
DD3	51%	29%	30%

Table 4. Summary of PH reduction for DD sites by scenario

Additionally, the results for S1 and S2 both include a small number of drainage areas in which relatively large treatment volumes are proposed to achieve over 90% phosphorus removal, whereas S0 has no individual units treating large enough volumes to reach this removal percentage. The optimization tool is extremely beneficial in identifying units that are both over- and under-utilized.

In Scenario 0, DD drainage areas were designed to meet a 51% reduction, but in the optimized scenarios target reductions for these sites were not fixed. Table 4, below, summarizes the resulting target reductions for these three sites (DD1 is subdivided into two sub-drainage areas for design reasons, see pages 18-19) from each of the modeling scenarios. The Scenario 2 results exemplify a situation in which it may be less costly for the overall stormwater management plan to have sites DD1 and DD2 construct larger infiltration basins to reduce the phosphorous load by greater than 51% (plus 14% through non-structural stormwater controls for a total of 65%).

Stormwater Control	S0	S1	S2
Bioretention System	4	4	2
Infiltration trench	2	3	0
Rain Garden	2	2	2
Infiltration Basin	6	16	14
Infiltration Chamber	1	1	1
Green Street/Tree Filters	0	0	0
Vegetated Swale	0	0	0
Gravel Wetland	0	0	0
Wet Extended Detention Basin	0	0	0
Dry Extended Detention Basin	0	0	0

Table 5. Stormwater control type by scenario

Conversely, if the owners of sites DD1 and DD2 are opposed to incorporating some stormwater controls because of existing conditions on their property, it may make sense for them to employ smaller units as suggested in Scenario 1 and financially assist other sites in achieving greater reductions to make up the difference. A watershed-wide optimization model can help guide these types of real world decisions. The various modeling scenarios also differed in the types of stormwater controls employed in each drainage area. In Scenarios 0 and 1, the stormwater control type was fixed, however, Scenario 1 proposes implementation of more stormwater controls than Scenario 0. In Scenario 2, the stormwater type was selected through the optimization program. Table 5 summarizes the stormwater control types selected in each scenario.

The most cost-efficient stormwater controls for phosphorus removal are those systems that have a high efficiency of phosphorus removal and a low construction cost per volume of water treated. Figure 14 in Appendix B illustrates the cost-effectiveness ($/ft2 of treated area) of various stormwater controls for the removal of 65% total phosphorus. Infiltration basins have very high phosphorus removal efficiency and a moderate cost so they end up being small, cost-effective systems for removing phosphorus. In contrast, dry extended detention basins are cheap controls to construct but have very low phosphorus removal efficiency, and therefore end up being very large, so they are not cost-effective for phosphorus

CONCLUSION

This valuable study provides a model for municipalities throughout the Charles River watershed by demonstrating how a small area within the watershed can be brought into compliance within the Upper/ Middle Charles River Nutrient TMDL using low impact development stormwater management treatment systems.

CRWA's *Stormwater Management Plan for the Town of Bellingham* identifies multiple opportunity sites where stormwater controls can be sited to effectively treat stormwater runoff. The results of our model display how various sites can be designed to work together to achieve TMDL compliance on the subwatershed or watershed scale. By using an optimization program, we were able to look at multiple scenarios. This tool is a valuable asset, and can help guide decisions about how to most effectively utilize structural stormwater controls within a region.

CRWA intends this plan to be a guide for the Town of Bellingham, the municipality can compare and contrast the results of the various optimization scenarios to develop a final, long-term stormwater management plan for this neighborhood. A long-term plan allows the municipality to act on implementation opportunities as they arise, either through regularly scheduled capital investment projects or grant opportunities.

As new or redevelopment occurs in the study area, new information of standards are put in place or thecurrent circumstances change, the plan would need to be updated but the methodology established by the study would still remain viable.

NEXT STEPS

The Town of Bellingham and local property owners affected by designated discharge permits can use this information to guide decisions about bringing the municipality as a whole or just individual private sites into compliance with the Upper/Middle Charles River Nutrient TMDL.

While this study didn't use DEP's Vulnerable Wetlands Atlas (available on request from Alice Smith at Mass. DEP) as a refrence, given the overlapping timing of the two efforts, the Town of Bellingham should refer to the Atlas which identifies vernal pools, 1st order streams etc. for prioritizing the retrofit projects to implement.

If additional funding becomes available, CRWA would like the opportunity to run optimizations with the phosphorus reduction goal set higher to explore the maximum, cost-efficient removal target for this area. Another obvious next step is to expand the scale of this assessment, design and modeling process to produce a town-wide or regional TMDL compliance plan.

Figure 14. Field investigation and documentation of stormwater infrastructure

LESSONS LEARNED

CRWA learned many valuable lessons throughout this project.

Coordination. Close coordination and cooperation between personnel from the Town, Nitsch Engineering and CRWA was essential to making this project a success. The project team experienced some minor delays due to lack of or difficulty with coordination at a few points throughout the project. It is difficult to anticipate these types of delays, however, in the future CRWA will likely budget more time into future project timelines specifically for project management and coordination. We learned that when multiple parties are involved it is essential to budget adequate time for relationship building, back and forth communication, and decision making. Whether it involves negotiating contracts at the start of a project or agreeing upon a methodology for calculating stormwater control treatment volumes, it is important to have the time to properly address these issues at the start of the relevant project phase to avoid conflict or discrepancies later in the project. Building time into the project timeline for project management allows you to do this without jeopardizing the project timeline.

Importance of good data. Stormwater infrastructure mapping data was missing for portions of the study area. Lack of essential data such as this that makes it difficult to determine exactly how and where stormwater is flowing makes siting and designing stormwater treatment systems difficult. CRWA worked with a private consultant hired by the Town of Bellingham to conduct field investigations of stormwater infrastructure and enter pipe, catch basin and manhole locations into a GIS. Due to funding from this project, the Town and CRWA were able to investigate more of the study area than would have otherwise been possible, however, we were not able to map the entire study area. Additionally, the project team did not have funding to conduct actual soil tests in the study area, soil information is based on Natural Resources Conservations Service (NRCS) maps which provide good guidance on likely soil type and water table levels but cannot be relied upon for accuracy at the site level. Where data gaps exist, CRWA has become adept at using the best available information to make reasonable assumptions that allow us to move forward in developing designs, however, between the conceptual designs presented here and implementation additional data like soils, depth to groundwater, infiltration rate etc. would need to be collected for each individual site.

Look for treatment opportunities wherever possible and opt for systems that best target the pollutants of concern. The optimized model run reinforced the importance of treating runoff from all areas, even if only a small volume can be treated. Treating a large volume of water from one drainage area does not always compensate for leaving large areas untreated. Treating the first flush and small storms is a necessary strategy to reduce nutrient loading in the Charles River watershed. Additionally, the optimized model underscores the importance of selecting stormwater control systems based on an area's water quality goals. Scenario 2 resulted in the selection of systems that have a high efficiency of phosphorus removal and a low construction cost per volume of water treated.

REFERENCES

Charles River Watershed Association (CRWA), 2009. *Draft Total Maximum Daily Load for Nutrients in the Upper/Middle Charles River, Massachusetts*. Control Number CN 272.0. Prepared for Massachusetts Department of Environmental Protection and United States Environmental Protection Agency, Project No. 2004-04/319. Charles River Watershed Association, Weston, Massachusetts.

Charles River Watershed Association (CRWA), 2010 *Stormwater Management Plan for Spruce Pond Brook Subwatershed.* Charles River Watershed Association, Weston, Massachusetts.

Center for Watershed Protection (CWP), 2007. *Manual 3: Urban Stormwater Retrofit Practices. Center for Watershd Protection.*

Claytor, Richard. 2010. Personal communication with Richard Claytor, Horsley Witten Group, Sandwich, MA

Environmental Protection Agency (EPA), 1999. *Preliminary Data Summary of Urban Stormwater Best Management Practices*. US Environmental Protection Agency.

Massachusetts Department of Environmental Protection (MassDEP), 2008. *Massachusetts Stormwater Handbook*.

Massachusetts Office of Geographic Information (MassGIS), 2010. http://www.mass.gov/mgis/

Natural Resources Conservation Service (NRCS), 2010. Soil Survey.

North Carolina State University (NCSU), 2003. *An Evaluation of Costs and Benefits of Structural Stormwater Best Management Practices in North Carolina*. NC State University.

Penn State University, *CREP Weed Management Factsheet*. Vegetation Management. Department of Horticulture, College of Agricultural Sciences http://vm.cas.psu.edu

TetraTech, 2009. *Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities*. Prepared for United States Environmental Protection Agency and Massachusetts Department of Environmental Protection. Tetra Tech, Inc., Fairfax, Virginia.

TetraTech, 2010. *Stormwater Best Management Practices (BMP) Performance Analysis.* Prepared for United States Environmental Protection Agency. Tetra Tech, Inc., Fairfax, Virginia.

University of New Hampshire Stormwater Center (UNHSC), 2007. UNHSC *2007 Annual Report*. University of New Hampshire Stormwater Center, Durham, New Hampshire.

Vermont Agency of Natural Resources (VTANR), 2002. *The Vermont Stormwater Management Manual*.

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SUBWATERSHED MANAGEMENT PLAN FOR BELLINGHAM, MA- APPENDICES

Modeling Results- Scenario 0

ID	Name	Total Area (ac)	Total Impervious Area (ac)	Existing Phosphorus Load (lb/yr)	RDA Site?	Assigned BMP Type	BMP Design Storm (in)	BMP Design Height (ft)	BMP Design Depth (ft)	BMP Area (sq. ft.)	BMP Treatment Volume (cu. ft.)	Phosphorus Reduction (%)	Phosphorus Load Removed (lb/yr)	Estimated BMP Cost ($)	Estimated Land Cost ($)	Total Cost ($)	($/lb/yr) Phosphorus Removed	($/ac) Acres Treated
DD1-A	Bellingham Plaza LLC (parking)	4.49	4.11	9.28	Yes	Bioret	0.38	0.75	3	4,168	5,418	50.9%	4.73	108,358	0	108,358	22,932	27,588
DD1-B	Bellingham Plaza LLC (roof)	3.12	1.60	3.86	Yes	ITrench	0.24	0	3	1,086	1,408	50.9%	1.97	22,527	0	22,527	11,449	14,114
DD2	26 Main St. Bell Rlt	4.48	2.75	6.52	Yes	Bioret	0.38	0.75	3	2,863	3,722	50.9%	3.32	74,438	0	74,438	22,426	27,588
DD3	Roman Catholic Church	30.51	2.20	7.86	Yes	Bioret	0.38	2	0	3,624	4,832	50.9%	4.00	72,487	0	72,487	18,115	20,691
O16	East of Mill Street	2.17	1.53	3.05	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O18-A	Park on North Main St and Mendon St	23.51	9.49	21.33	No	IBasin	0.36	4	0	9,260	12,721	73.5%	15.68	76,324	0	76,324	4,867	7,854
O18-B	Park on North Main St and Mendon St	6.52	2.34	6.31	No	Raingdn	0.23	0.75	0	3,526	2,048	58.1%	3.66	15,362	0	15,362	4,193	6,326
O18-C	Park on North Main St and Mendon St	4.49	1.45	2.89	No	Bioret	0.20	0.75	3	852	1,108	34.0%	0.98	16,620	0	16,620	16,890	10,890
O18-D	Park on North Main St and Mendon St	1.75	1.46	3.33	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O18-E	Park on North Main St and Mendon St	1.15	0.70	1.54	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O2	Edgehill Ln - cul-de-sac	1.68	0.49	0.76	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O20	Behind Rail intersects w/ North Main St	10.15	1.12	2.54	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O21	Rose Avenue	4.48	1.44	2.59	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O22	Judy Ln - cul-de-sac	2.62	0.86	1.52	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O24	Municipal Center	0.68	0.68	0.62	No	ITrench	0.48	2	0	615	1,125	79.5%	0.49	13,502	0	13,502	27,599	20,918
O24-A	Municipal Center	0.11	0.11	0.10	No	Raingdn	0.70	0.75	0	270	269	85.7%	0.09	2,020	0	2,020	23,586	18,982
O25	Famous Pizza parking lot	1.00	0.99	1.82	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O26	North Main Street	0.36	0.32	0.29	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O28	Municipal Center	2.98	2.19	4.37	No	IBasin	0.48	2	0	4,048	3,703	85.7%	3.75	22,215	0	22,215	5,927	10,459
O28-A	Walgreens	1.91	1.88	2.55	No	IChamber	0.66	0	3	2,215	4,306	85.6%	2.19	0	0	0	0	0
O29	Auto Dealer on North Main St	2.48	0.97	1.87	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O4	Woodside Ln - cul-de-sac	1.95	0.58	0.99	No	IBasin	0.21	2	0	671	475	58.1%	0.58	570	0	570	987	924
O5	Centerville Ln - cul-de-sac	4.95	1.29	2.78	No	IBasin	0.27	2	0	1,535	1,404	72.2%	2.01	1,685	0	1,685	838	1,195
O6	Toni and Jamie Dr - cul-de-sac	4.92	1.15	1.49	No	IBasin	0.61	1	0	7,559	2,825	85.1%	1.27	3,390	0	3,390	2,669	2,638
S1	Natural area north of River Brook Rd	4.70	0.63	0.92	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
S2	Riverbrook Road - Rail tracks	17.47	5.07	8.26	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
S3	Riverine buffer zone	61.20	7.16	15.30	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
S4	Thayer St/Creek Central	26.97	5.57	11.06	No	IBasin	0.28	2	0	9,007	6,369	64.3%	7.11	38,216	0	38,216	5,376	6,006
S5	Undeveloped area north of Depot St	3.89	0.29	0.81	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
	TOTALS	236.70	60.43	126.65								40.9%	51.82	467,715	0	467,715	9,026	7,063

ID	Name	Total Area (ac)	Total Impervious Area (ac)	Existing Phosphorus Load (lb/yr)	RDA Site?	Assigned BMP Type	BMP Design Storm (in)	BMP Design Height (ft)	BMP Design Depth (ft)	BMP A rea (sq. ft.)	BMP Treatment Volume (cu. ft.)	Phosphorus Reduction (%)	Phosphorus Load Removed (lb/yr)	Estimated BMP Cost ($)	Estimated Land Cost at $2/ft2 ($)	Total Cost ($)	($/lb/yr) Phosphorus Removed	($/ac) Acres Treated
DD1-A	Bellingham Plaza LLC (parking)	4.49	4.11	9.28	Yes	Bioret	0.02	0.75	3	265	345	4.8%	0.44	6,892	0	6,892	15,519	1,755
DD1-B	Bellingham Plaza LLC (roof)	3.12	1.60	3.86	Yes	ITrench	0.14	0	3	638	511	34.8%	1.34	13,237	0	13,237	9,856	8,294
DD2	26 Main St. Bell Rlt	4.48	2.75	6.52	Yes	Bioret	0.02	0.75	3	136	176	3.6%	0.23	3,527	0	3,527	15,177	1,307
DD3	Roman Catholic Church	30.51	2.20	7.86	Yes	Bioret	0.17	2	0	1,584	2,111	29.2%	2.29	31,672	0	31,672	13,814	9,041
O16	East of Mill Street	2.17	1.53	3.05	No	IBasin	0.20	2	0	1,508	1,005	55.5%	1.69	6,397	4,523	10,920	6,457	7,332
O18-A	Park on North Main St and Mendon St	23.51	9.49	21.33	No	IBasin	0.27	4	0	6,915	9,220	64.4%	13.74	56,999	0	56,999	4,149	5,866
O18-B	Park on North Main St and Mendon St	6.52	2.34	6.31	No	Raingdn	0.27	0.75	0	4,113	2,056	61.5%	3.88	17,918	0	17,918	4,618	7,379
O18-C	Park on North Main St and Mendon St	4.49	1.45	2.89	No	Bioret	0.07	0.75	3	285	370	13.2%	0.38	5,553	0	5,553	14,502	3,638
O18-D	Park on North Main St and Mendon St	1.75	1.46	3.33	No	IBasin	0.41	4	0	1,315	1,753	85.2%	2.84	12,477	3,945	16,423	5,782	11,726
O18-E	Park on North Main St and Mendon St	1.15	0.70	1.54	No	IBasin	0.24	4	0	378	504	72.5%	1.12	3,589	1,135	4,724	4,217	6,895
O2	Edgehill Ln - cul-de-sac	1.68	0.49	0.76	No	IBasin	0.11	2	0	288	192	39.6%	0.30	1,223	865	2,087	6,904	3,948
O20	Behind Rail intersects w/ North Main St	10.15	1.12	2.54	No	IBasin	0.24	4	0	827	1,102	72.3%	1.84	7,844	2,480	10,324	5,615	6,825
O21	Rose Avenue	4.48	1.44	2.59	No	IBasin	0.27	2	0	1,643	1,096	72.0%	1.87	6,013	4,930	10,943	5,862	7,209
O22	Judy Ln - cul-de-sac	2.62	0.86	1.52	No	IBasin	0.15	2	0	675	450	46.5%	0.71	1,911	2,026	3,937	5,573	4,350
O24	Municipal Center	0.68	0.68	0.62	No	ITrench	0.02	2	0	20	27	4.5%	0.03	440	0	440	15,889	681
O24-A	Municipal Center	0.11	0.11	0.10	No	Raingdn	0.41	0.75	0	157	79	72.6%	0.07	1,174	0	1,174	16,190	11,034
O25	Famous Pizza parking lot	1.00	0.99	1.82	No	IBasin	0.13	2	0	499	333	49.6%	0.90	2,737	1,496	4,234	4,703	4,481
O26	North Main Street	0.36	0.32	0.29	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	1
O28	Municipal Center	2.98	2.19	4.37	No	IBasin	0.29	2	0	2,466	1,644	73.4%	3.21	13,535	0	13,535	4,213	6,372
O28-A	Walgreens	1.91	1.88	2.55	No	IChamber	0.66	0	3	2,215	2,658	85.6%	2.19	0	0	0	0	0
O29	Auto Dealer on North Main St	2.48	0.97	1.87	No	IBasin	0.17	2	0	689	460	56.8%	1.06	3,783	2,068	5,851	5,494	5,865
O4	Woodside Ln - cul-de-sac	1.95	0.58	0.99	No	IBasin	1.05	2	0	3,325	2,217	95.3%	0.95	2,821	0	2,821	2,981	4,577
O5	Centerville Ln - cul-de-sac	4.95	1.29	2.78	No	IBasin	0.82	2	0	4,570	3,046	95.6%	2.66	5,016	0	5,016	1,886	3,558
O6	Toni and Jamie Dr - cul-de-sac	4.92	1.15	1.49	No	IBasin	0.84	1	0	10,426	3,475	91.2%	1.36	4,677	0	4,677	3,434	3,638
S1	Natural area north of River Brook Rd	4.70	0.63	0.92	No	ITrench	0.02	0	3	41	33	4.5%	0.04	644	124	768	18,478	961
S2	Riverbrook Road - Rail tracks	17.47	5.07	8.26	No	ITrench	0.00	0	3	0	0	0.0%	0.00	10	1	10	10	100
S3	Riverine buffer zone	61.20	7.16	15.30	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
S4	Thayer St/Creek Central	26.97	5.57	11.06	No	IBasin	0.20	2	0	6,373	4,249	55.1%	6.10	27,039	0	27,039	4,434	4,250
S5	Undeveloped area north of Depot St	3.89	0.29	0.81	No	IBasin	0.26	2	0	475	317	70.2%	0.57	2,608	1,426	4,034	7,086	8,787
	TOTALS	236.70	60.43	126.65								40.9%	51.82	239,731	25,020	264,745	5,109	4,006

Modeling Results- Scenario 2

ID	Name	Total Area (ac)	Total Impervious Area (ac)	Existing Phosphorus Load (lb/yr)	RDA Site?	Assigned BMP Type	BMP Design Storm (in)	BMP Design Height (ft)	BMP Design Depth (ft)	BMP Area (ft2)	BMP Treatment Volume (ft3)	Phosphorus Reduction (%)	Phosphorus Load Removed (lb/yr)	Estimated BMP Cost ($)	Estimated Land Cost at $2/ft2 ($)	Total Cost ($)	($/lb/yr) Phosphorus Removed	($/ac) Acres Treated
DD1-A	Bellingham Plaza LLC (parking)	4.49	4.11	9.28	Yes	Bioret	0.38	0.75	3	3,024	2,716	59.1%	5.49	21,725	0	21,725	3,960	5,531
DD1-B	Bellingham Plaza LLC (roof)	3.12	1.60	3.86	Yes	ITrench	0.15	0	3	1,456	944	51.2%	1.98	7,550	0	7,550	3,815	4,730
DD2	26 Main St. Bell Rlt	4.48	2.75	6.52	Yes	Bioret	0.38	0.75	3	3,002	2,252	64.0%	4.17	18,014	0	18,014	4,319	6,676
DD3	Roman Catholic Church	30.51	2.20	7.86	Yes	Bioret	0.38	2	0	1,613	2,150	29.6%	2.33	32,257	0	32,257	13,862	9,207
O16	East of Mill Street	2.17	1.53	3.05	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O18-A	Park on North Main St and Mendon St	23.51	9.49	21.33	No	IBasin	0.35	4	0	5,255	7,219	57.8%	12.34	43,313	0	43,313	3,510	4,457
O18-B	Park on North Main St and Mendon St	6.52	2.34	6.31	No	Raingdn	0.20	0.75	0	8,127	2,361	61.2%	3.86	14,164	0	14,164	3,668	5,833
O18-C	Park on North Main St and Mendon St	4.49	1.45	2.89	No	Bioret	0.20	0.75	3	294	382	13.6%	0.39	5,724	0	5,724	14,502	3,751
O18-D	Park on North Main St and Mendon St	1.75	1.46	3.33	No	IBasin	0.00	4	0	381	603	51.1%	1.70	3,617	1,144	4,761	2,796	3,399
O18-E	Park on North Main St and Mendon St	1.15	0.70	1.54	No	IBasin	0.00	4	0	370	585	71.9%	1.11	3,510	1,110	4,620	4,160	6,744
O2	Edgehill Ln - cul-de-sac	1.68	0.49	0.76	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O20	Behind Rail intersects w/ North Main St	10.15	1.12	2.54	No	IBasin	0.00	4	0	483	764	54.8%	1.39	4,583	1,449	6,032	4,332	3,988
O21	Rose Avenue	4.48	1.44	2.59	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O22	Judy Ln - cul-de-sac	2.62	0.86	1.52	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O24	Municipal Center	0.68	0.68	0.62	No	ITrench	0.35	2	0	464	425	57.9%	0.36	2,548	0	2,548	7,149	3,947
O24-A	Municipal Center	0.11	0.11	0.10	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O25	Famous Pizza parking lot	1.00	0.99	1.82	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
O26	North Main Street	0.36	0.32	0.29	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	2	2	4	0	13
O28	Municipal Center	2.98	2.19	4.37	No	IBasin	0.35	2	0	2,146	1,963	69.2%	3.03	11,779	0	11,779	3,891	5,546
O28-A	Walgreens	1.91	1.88	2.55	No	IChamber	0.41	0	3	2,215	4,306	85.6%	2.19	0	0	0	0	0
O29	Auto Dealer on North Main St	2.48	0.97	1.87	No	IBasin	0.00	2	0	231	422	43.4%	0.81	3,165	692	3,857	4,739	3,866
O4	Woodside Ln - cul-de-sac	1.95	0.58	0.99	No	IBasin	0.20	2	0	2,924	2,067	93.6%	0.93	2,481	0	2,481	2,670	4,024
O5	Centerville Ln - cul-de-sac	4.95	1.29	2.78	No	IBasin	0.20	2	0	4,603	4,211	95.7%	2.66	5,053	0	5,053	1,898	3,584
O6	Toni and Jamie Dr - cul-de-sac	4.92	1.15	1.49	No	IBasin	0.54	1	0	8,488	3,173	88.0%	1.31	3,807	0	3,807	2,898	2,962
S1	Natural area north of River Brook Rd	4.70	0.63	0.92	No	ITrench	0.00	0	3	54	71	7.7%	0.07	529	163	693	9,777	866
S2	Riverbrook Road - Rail tracks	17.47	5.07	8.26	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
S3	Riverine buffer zone	61.20	7.16	15.30	No	None	0.00	0.5	3	0	39,739	0.0%	0.00	0	0	0	0	0
S4	Thayer St/Creek Central	26.97	5.57	11.06	No	IBasin	0.26	2	0	5,694	4,027	51.5%	5.70	24,159	0	24,159	4,240	3,797
S5	Undeveloped area north of Depot St	3.89	0.29	0.81	No	None	n/a	n/a	n/a	n/a	n/a	0.0%	0.00	0	0	0	0	0
	TOTALS	236.70	60.43	126.65								40.9%	51.82	207,980	4,560	212,536	4,101	3,210

APPENDIX B: TECHNICAL INFORMATION

CRWA's Modeling Analysis

CRWA used computer modeling to develop the stormwater management plan for the entire study area. Modeling allowed us to assess the phosphorus reduction potential of various design scenarios for the study area (See Section: Modeling Analysis). This section contains technical details on certain relevant aspects of the modeling process, including CRWA's methodology for sizing and costing stormwater control units. NEI developed the schematic designs for the ten drainage areas presented in the Proposed Stormwater Management Design section. CRWA, in modeling the study area, and NEI, in developing the designs calculated the size and cost of stormwater control units sizes independently using the same water quality volume but with two different methods. NEI's methodology is discussed in the following section.

Calculating Existing Phosphorus Loads for Modeling Analysis

Phosphorus loads were developed by TetraTech (2009) specifically for 2005 land use categories. Although these export coefficients are slightly different from the Upper/Middle Charles TMDL coefficients (CRWA, 2009), which were based on the 1999 land use data, they preserve the total calibrated stormwater TMDL load. Our project ignored small variations in phosphorus loading across soil types. The land-use based export coefficients, multiplied by the pervious and impervious areas within each land use in each drainage area, yielded the estimated total phosphorus load for the study area under existing conditions.

Treatment of Existing Stormwater Control Units

CRWA investigated all existing stormwater control units that were accessible. CRWA determined that only one drainage area had a functioning stormwater control unit which was constructed after the completion of the Upper/Middle Nutrient TMDL study. Any control unit constructed prior to 2000 would be considered part of the TMDL "base conditions" and could not be counted as helping the Town reach their reduction goal. Drainage area O-28 has an underground infiltration chamber. Based on this system design and type, we estimated the system to achieve a 41% phosphorus removal rate for the drainage area it serves. As this is an existing installed system, the volume of water the system is treating (expressed as a depth over the contributing area) was fixed in both optimization scenarios.

Size Calculations

CRWA used the removal performance curves developed TetraTech (2009) to determine the phosphorus removal efficiencies as a function of the stormwater control volume. CRWA modified the approach used in this project from the one used in the Franklin assessment (CRWA,2010) based on a clarification by US-EPA on these curves. US-EPA has stated that the horizontal axis (expressed as a depth over the contributing area) is not the water quality volume rather it is the physical stormwater volume. In the Franklin project, we calculated the water quality volume directly from the curves. In this project we calculated the physical volume then estimated the water quality volume by adding back the estimated two-hour infiltration volume based on the Massachusetts Static Method (MA-DEP,

Table 6. BMP Sizing Formulas

BMP	Drain Time (days)	Porosity (-)	Area (A1)	S	Area (A2)	S
Bioretention	2	0.4	WQD * DA / (Dw+Dm*n)	1	WQD * DA * [Dm/ { Ksat* (0.5*Dw+Dm) *T }]	3
Green Streets	2	0.4	WQD * DA / (Dw+Dm*n)	1	WQD * DA * [Dm/ { Ksat* (0.5*Dw+Dm) *T }]	3
Gravel Wetland	-	0.4	WQD * DA / (Dw+Dm*n)	1	0.0035 * DA	4
Infiltration Basin	3	-	WQD * DA / (Dw+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Infiltration Chamber	3	-	WQD * DA / (Dm*n+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Infiltration Trench	3	0.45	WQD * DA / (Dm*n+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Rain Garden	1	-	WQD * DA / (Dw+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5

Sources (S):
1 = storage formula
2 = storage formula with 2 hours of infiltration using simple dynamic method from MA-DEP(2008)
3 = bioretention formula using Darcy's law (need ref)
4 = area formula (VT-ANR, 2002)
5 = drainage time formula

Definitions:
A = BMP area (ft2) = maximum(A1, A2)
DA = drainage area (ft2)
Dw = water depth (ft)
Dm = media depth (ft)
Ksat = saturated hydraulic conductivity (infiltration=soil, biofiltration/green streets=media)
T = design drainage time (d)
WQD = design water quality depth (ft)

Table 7. BMP Unit Costs and Cost Factors

BMP	Cost ($/ft^3)
Dry Pond	2
Wet Pond	3
Gravel Wetland	8
Infiltration Basin	4
Infiltration Trench	8
Infiltration Chamber	12
Rain Garden	5
Bioretention	10
Green Street	15
Water Quality Swale	8

BMP Type	Cost Factor
Outlet modifications	0.1
New BMP in undeveloped area	1
New BMP in partially developed area	1.5
New BMP in developed area	2
Insitu BMP retrofit of dry systems	2
Insitu BMP retrofit of wet systems	3

1999). The two volumes only differ for infiltration systems. The water quality volume was then for subsequent sizing and cost calculations like the Franklin project.

The physical area of the stormwater control was determined as the maximum of two area calculations (A1 and A2, see Table 3). The bioretention system area was determined as the maximum of the area from a common sizing formula based on Darcy's Law and the area required to store the entire design volume. For infiltration systems, first area was determined using the Massachusetts Static Method (MA-DEP, 1999) (area required to store the design volume allowing for two hours of infiltration) and an a second area that allows a three-day drainage recovery time. Rain gardens used a shallow infiltration basin design with a one day recovery time. For purposes of this analysis, to represent simpler versus more complex design opportunities, CRWA used a slightly different design standard for rain gardens and bioretention cells (see plan views page 43 and 44). Because these proposed stormwater controls are not located in areas under the jurisdiction of the Wetlands Protection Act, they may not fully comply with DEP stormwater design standards. In some cases, designs compliant with the standards were not the most cost effective, so alternative, more cost effective designs were selected. The final surface area of the stormwater control was estimated by multiplying the water quality area by a flood storage factor that varies from one to three depending on the estimated area required for flood control. These area calculations were only used to see if the stormwater control could be located on the available space at the site.

Stormwater Control Cost Calculations

Unit costs of new stormwater controls were estimated from literature sources as the cost per water quality volume treated. Design costs (5-35%) were ignored as they are usually a fixed percentage of the total construction cost. Adjustment factors (0.3-2) were used to convert these costs from new site construction to retrofit site costs with the assumption that retrofitting highly developed, dense properties may be more costly than placing stormwater controls on new or sparsely developed sites. Retrofit costs may be higher (factors>1.0) if sites are more constrained for machinery and there are utilities (pipes, cables etc) present on or near the site. A simple retrofit using an outlet modification had a very low factor (0.3). The construction cost for each stormwater control was determined from the water quality volume (ft3), unit cost ($/ft3), and the cost factor (0.3-2). Land cost for stormwater controls requiring a land purchase (proposed site is on private property) was determined from unit land costs ($2/ft2) for current land sales in Bellingham and the land areas for the controls were estimated as 1.5 times the physical area of the stormwater control unit. The total cost for retrofitting the Bellingham study area the sum of the individual stormwater control costs for all units chosen to meet the 41% target phosphorus load reduction.

Table 8. BMP Unit Costs and Cost Factors

BMP	Cost ($/ft^3)
Dry Pond	2
Wet Pond	3
Gravel Wetland	8
Infiltration Basin	4
Infiltration Trench	8
Infiltration Chamber	12
Rain Garden	5
Bioretention	10
Green Street	15
Water Quality Swale	8

BMP Type	Cost Factor
Outlet modifications	0.1
New BMP in undeveloped area	1
New BMP in partially developed area	1.5
New BMP in developed area	2
Insitu BMP retrofit of dry systems	2
Insitu BMP retrofit of wet systems	3

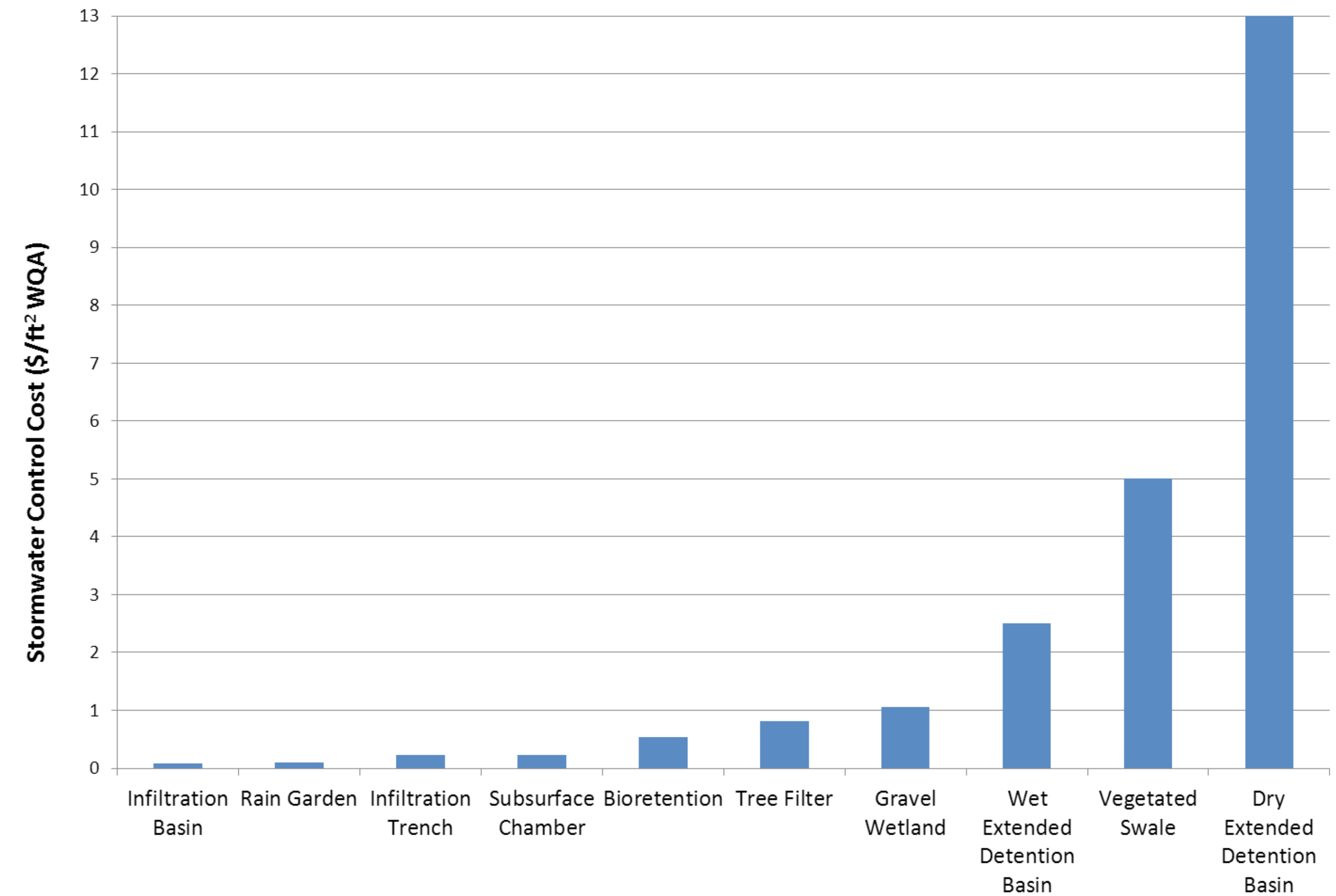


Figure 15. Relative Costs of Stormwater Controls for 65% Phosphorus Removal

Stormwater Control Cost Calculations by NEI

As opposed to CRWA's mehtodology of estimating unit costs of new stormwater controls from literature sources as the cost per water quality volume treated. NEI provided costs based on design specifications for each individual stormwater control. Table 8 summarizes the costs for each stormwater control for each individual priority sites.

DD1-A **Bellingham Plaza LLC**

Parking Lot Drainage Area: Bioretention Basins

	Unit Cost	Unit	Quantity	Total Cost
Bioretention Basin	$ 9.46	sf	8990	$ 85,035
12" CPP Pipe	$ 17.19	lf	130	$ 2,235
Area Drains (OCS)	$ 2,173.61	ea	6	$ 13,042
			Total	$ 100,311

DD1-B **Bellingham Plaza LLC**

Roof Drainage Area: Infiltration Trenches (2' x 2')

	Unit Cost	Unit	Quantity	Total Cost
Inf. Trenches	$ 5.33	sf	1500	$ 7,993
			Total	$ 7,993

O18 A **North Main Street: Infiltration Basin w/ Sediment Forebay**

	Unit Cost	Unit	Quantity	Total Cost
Infiltration Basin	$ 2.68	sf	7960	$ 21,335
12" CPP Pipe	$ 17.19	lf	140	$ 2,407
Area Drain (OCS)	$ 2,173.61	ea	1	$ 2,174
			Total	$ 23,742

O18 B **Town Park on North Main Street: Bioretention Basin**

	Unit Cost	Unit	Quantity	Total Cost
Bioretention Basin	$ 3.98	sf	3840	$ 15,279
12" CPP Pipe	$ 17.19	lf	335	$ 5,759
Area Drains (OCS)	$ 2,173.61	ea	2	$ 4,347
			Total	$ 25,385

O18 C **South Main Street: Bioretention Basin**

	Unit Cost	Unit	Quantity	Total Cost
Bioretention Basin	$ 9.46	sf	1410	$ 13,337
12" CPP Pipe	$ 17.19	lf	263	$ 4,521
Area Drains (OCS)	$ 2,173.61	ea	1	$ 2,174
			Total	$ 20,032

O24 **Town Hall Rear: Infiltration Trench (3' x 4')**

	Unit Cost	Unit	Quantity	Total Cost
Inf. Trench	$ 9.56	sf	820	$ 7,837
			Total	$ 7,837

O24A **Town Hall Rear: Rain Garden**

	Unit Cost	Unit	Quantity	Total Cost
Rain Garden	$ 3.98	sf	420	$ 1,671
			Total	$ 1,671

O28 **Town Hall Front: Infiltration Basins w/ Sediment Forebays**

	Unit Cost	Unit	Quantity	Total Cost
Infiltration Basin-3'	$ 2.68	sf	1302	$ 3,490
Infiltration Basin-4'	$ 2.88	sf	1806	$ 5,206
12" CPP Pipe	$ 17.19	lf	200	$ 3,438
Area Drain (OCS)	$ 2,173.61	ea	2	$ 4,347
			Total	$ 12,133

O6 **Tonie and Jamie Drive: Basin Retrofit w/ Sediment Forebay**

	Unit Cost	Unit	Quantity	Total Cost
Basin Retrofit	$ 2.07	sf	7170	$ 14,868
			Total	$ 14,868

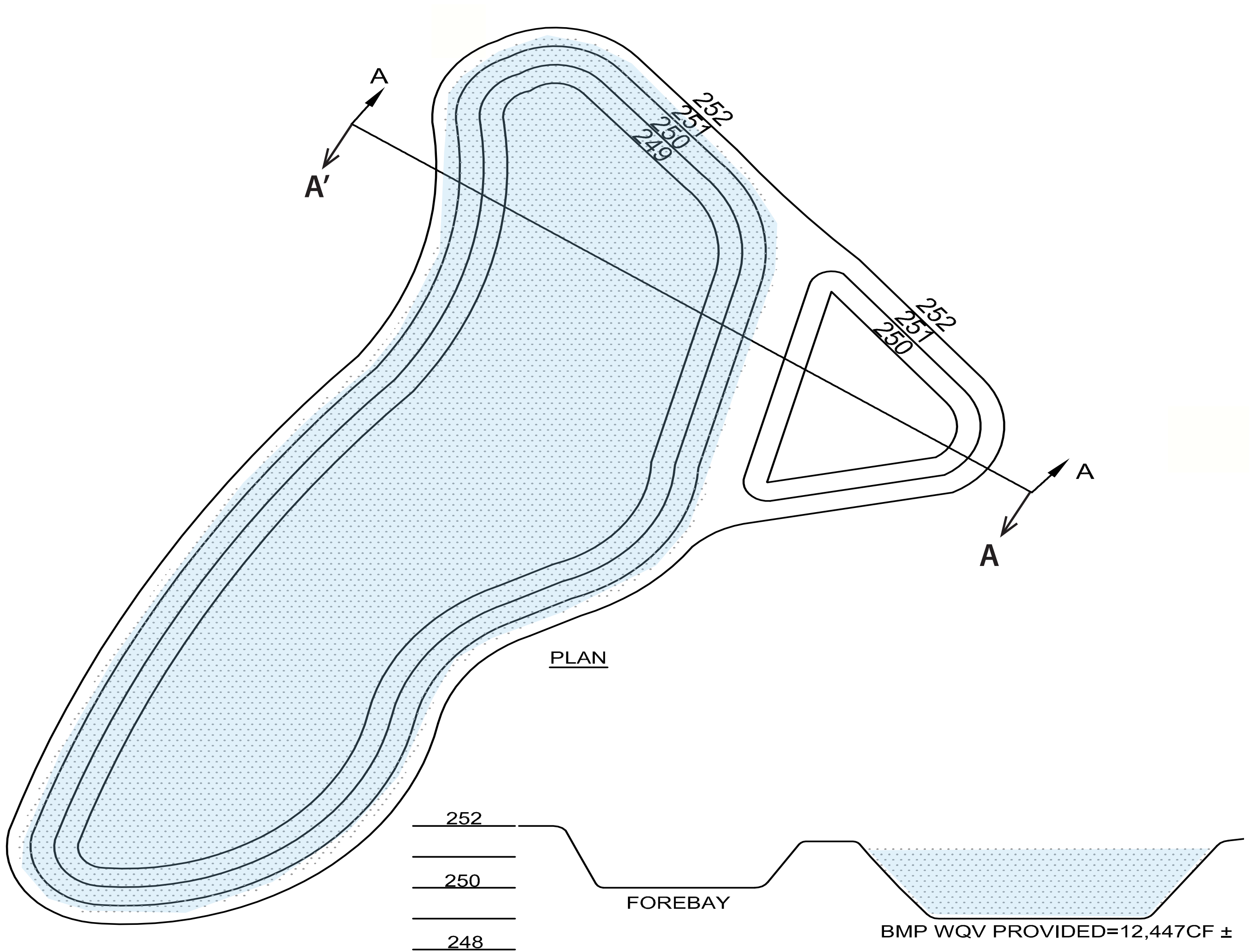
S4 **Thayer Street/Creek Central: Infiltration Basin w/ Sediment**

	Unit Cost	Unit	Quantity	Total Cost
Infiltration Basin	$ 2.68	sf	5100	$ 13,669
12" CPP Pipe	$ 17.19	lf	66	$ 1,135
Headwall (OCS)	$ 3,600.00	ea	1	$ 3,600
			Total	$ 14,804

Table 9. BMP Cost Information by drainage area.
Data supplied by NEI.

O18A NORTH MAIN STREET: INFILTRATION BASIN

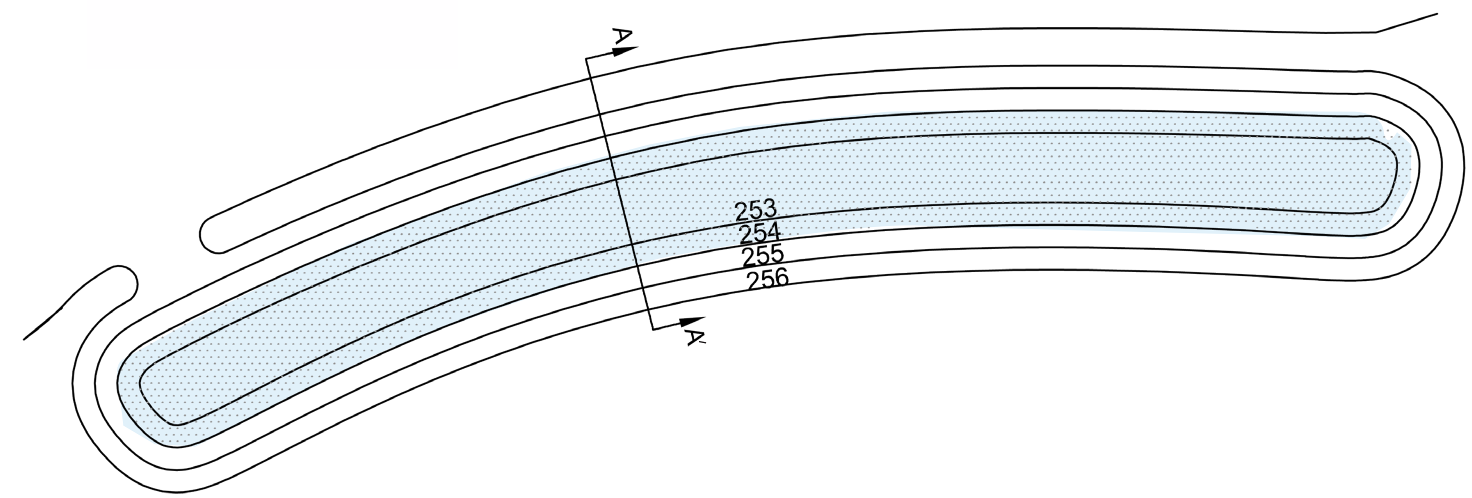
Infiltration Basin Plan

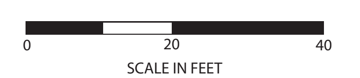


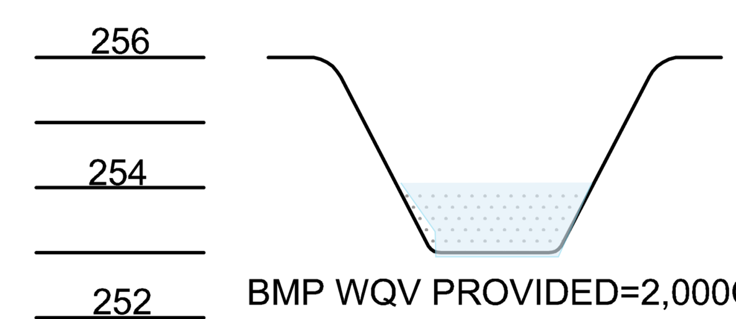
Section A - A'

O18 B TOWN COMMONS: RAIN GARDEN

Rain Garden Plan







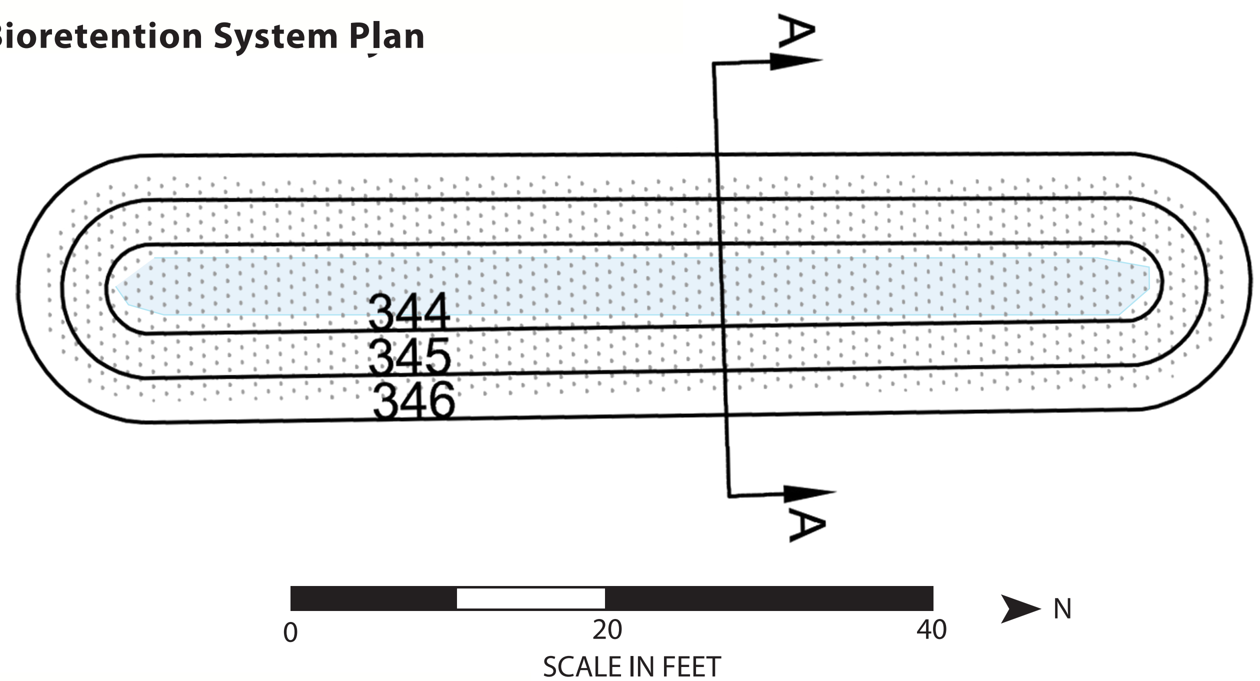
BMP WQV PROVIDED=2,000CF ±

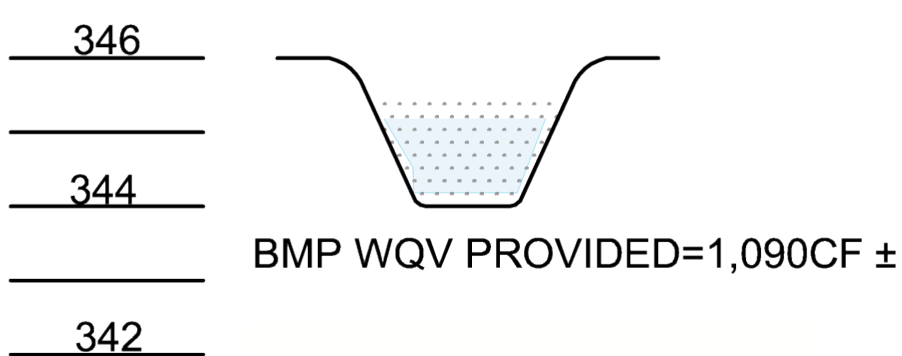
Section A - A'

Details provided by Nitsch Engineering

O18 C TOWN COMMONS: BIORETENTION SYSTEM

Bioretention System Plan

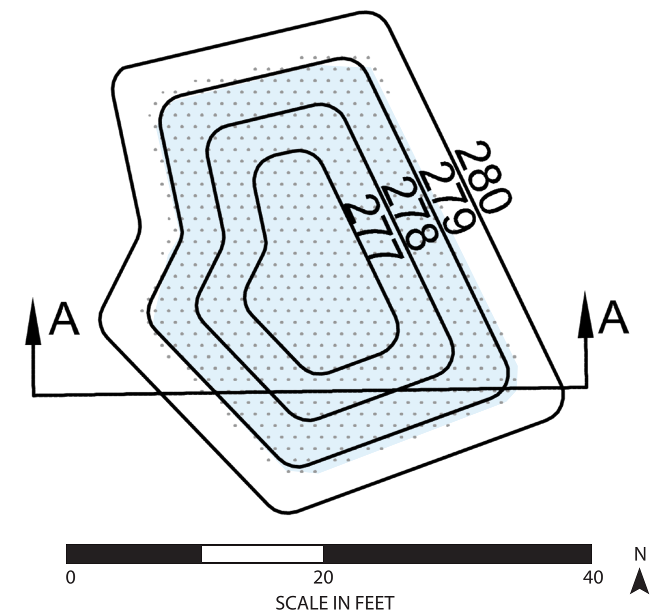


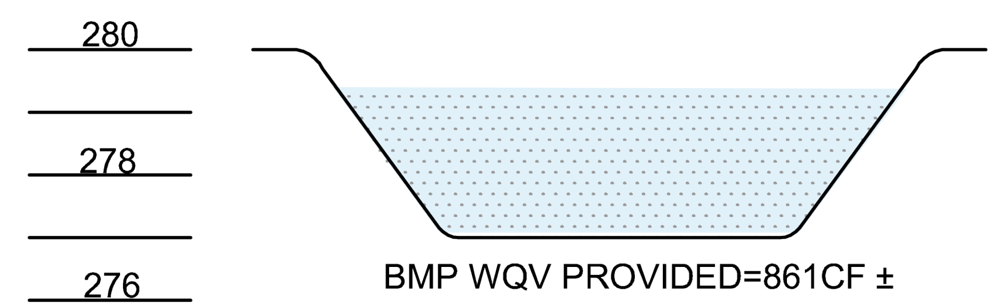


Section A - A'

O28C TOWN HALL FRONT: INFILTRATION BASINS

Infiltration Basin North of Town Hall: Plan View



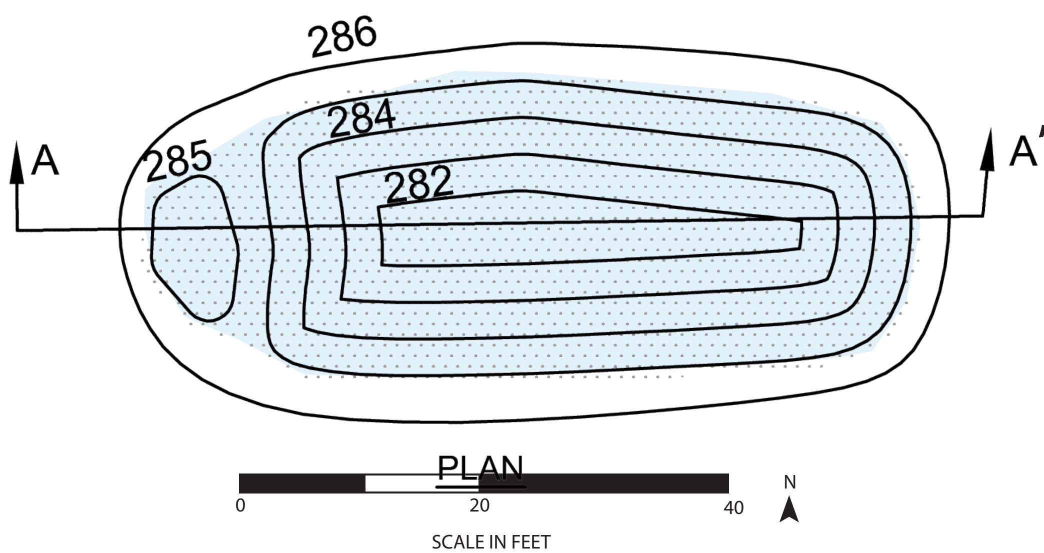


Section A-A'

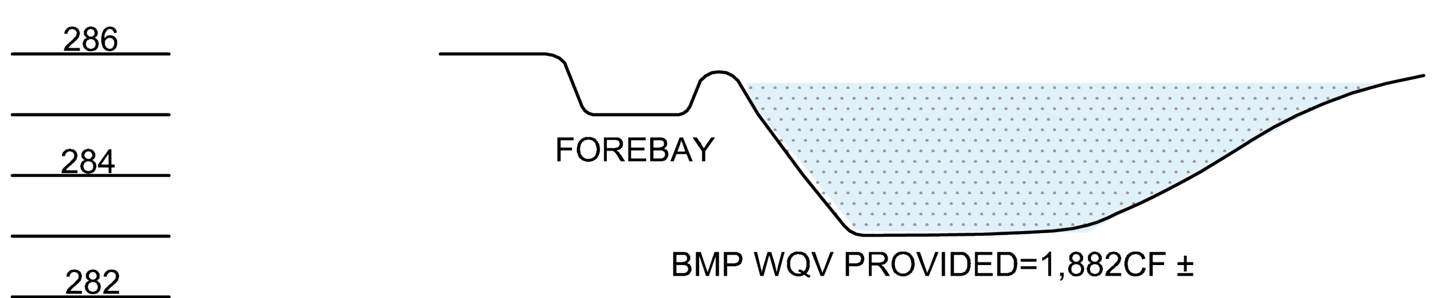
Details provided by Nitsch Engineering

O28 TOWN HALL REAR: INFILTRATION TRENCH

Infiltration Basin South of Town Hall: Plan View

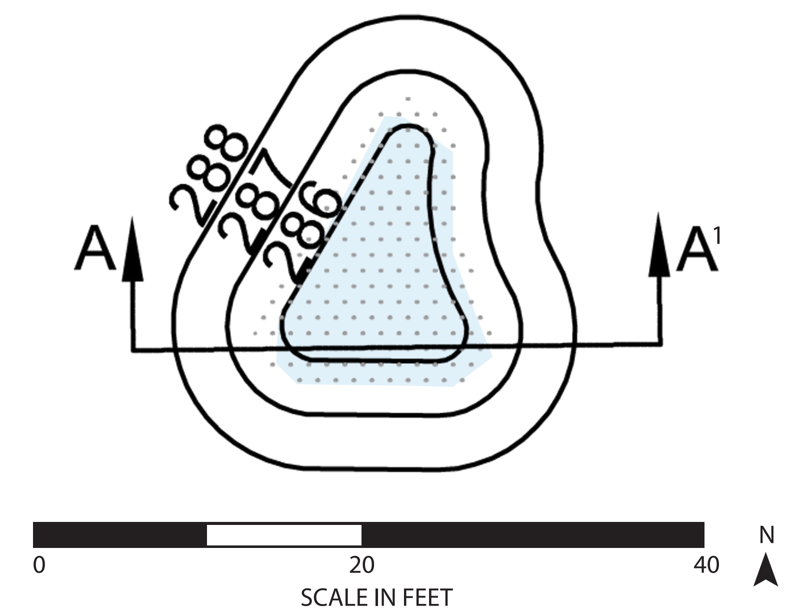


Section A-A'



O24A TOWN HALL REAR: RAIN GARDEN

Rain Garden Plan



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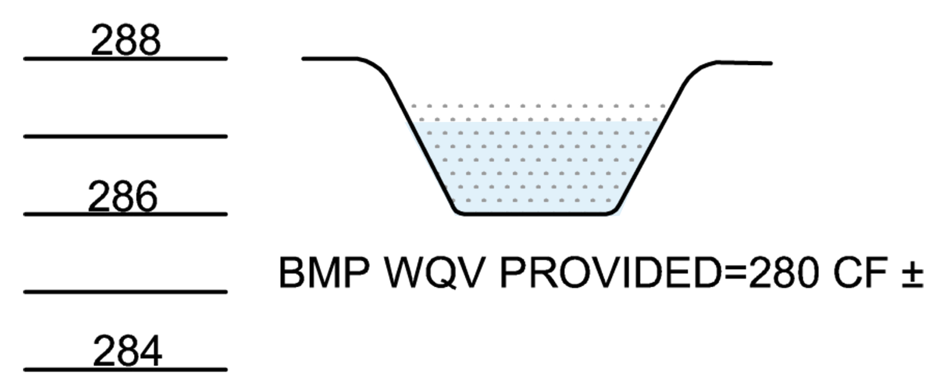
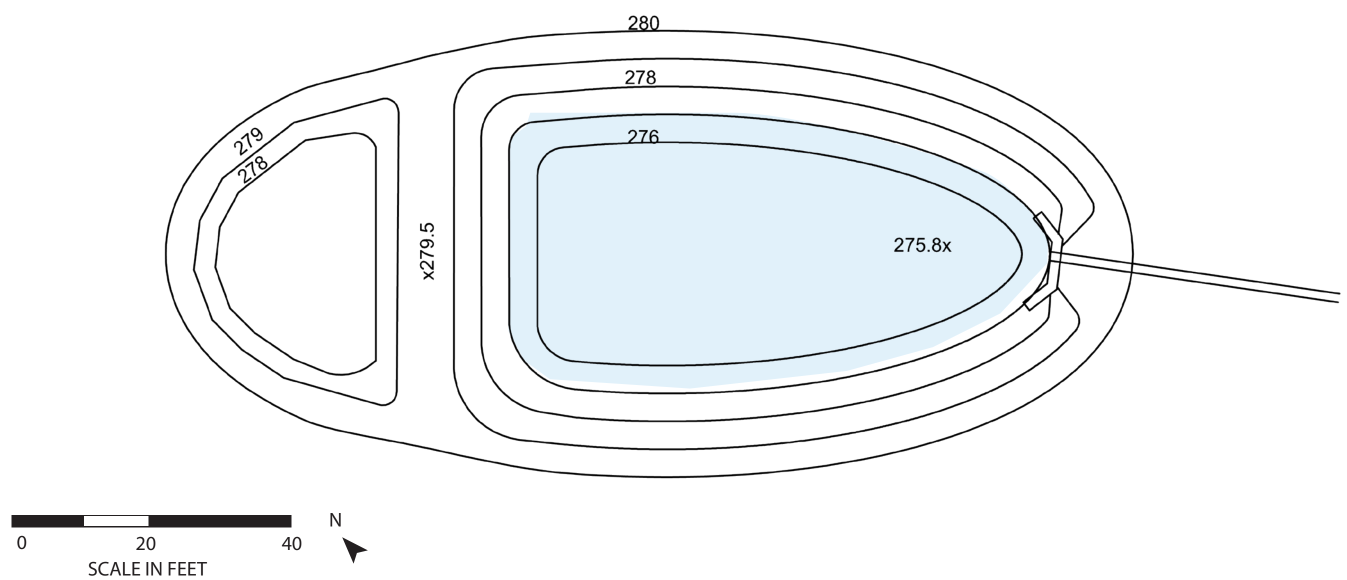


Details provided by Nitsch Engineering

Appendix C - Details

O6 TONI AND JAMIE DRIVE: BASIN RETROFIT

Basin Plan



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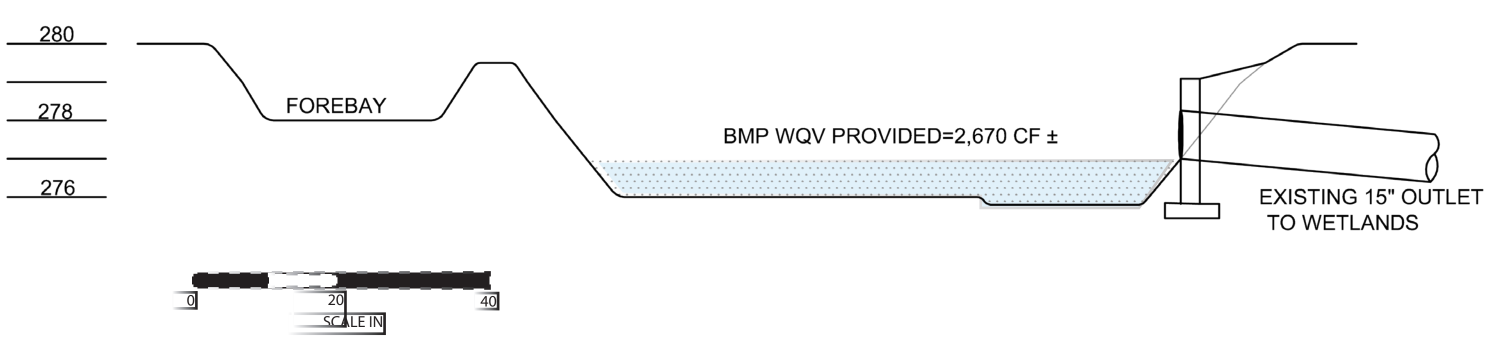
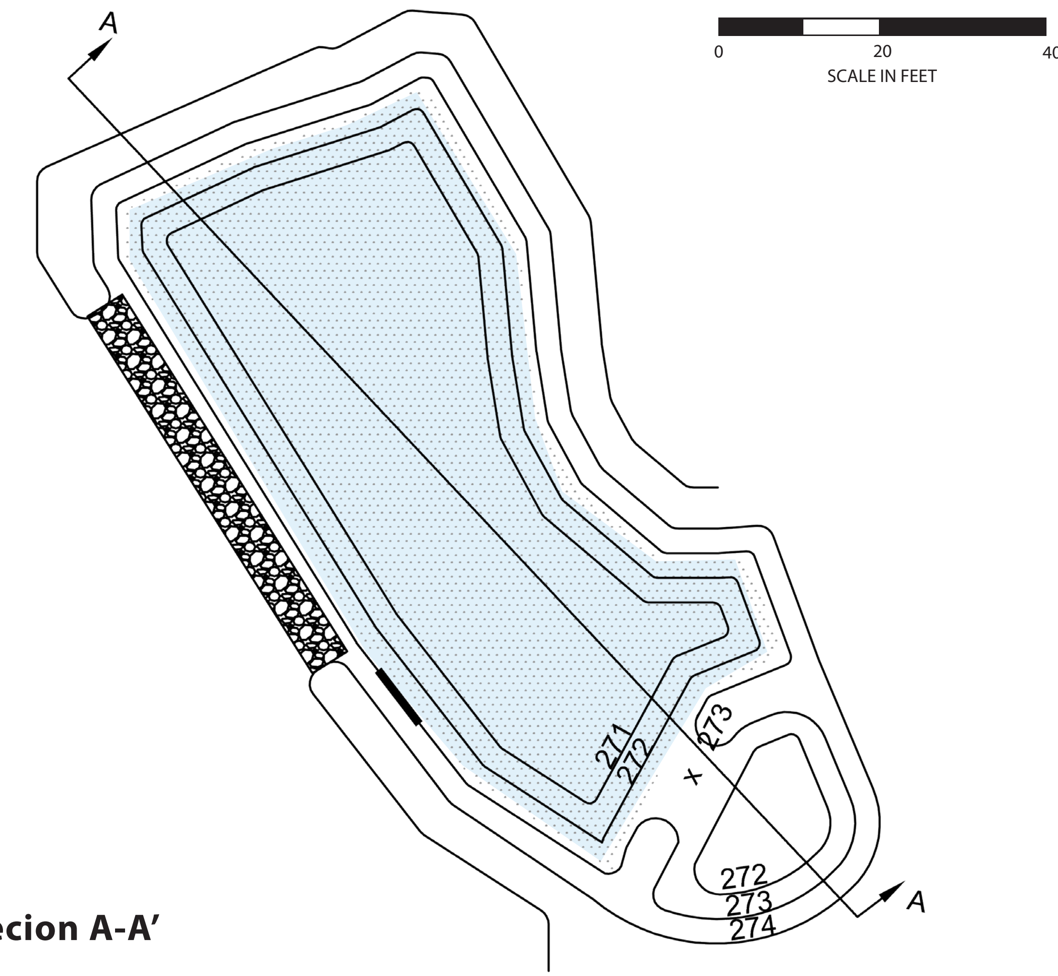


S4 THAYER ST/CREEK CENTRAL: INFILTRATION BASIN

Basin Plan



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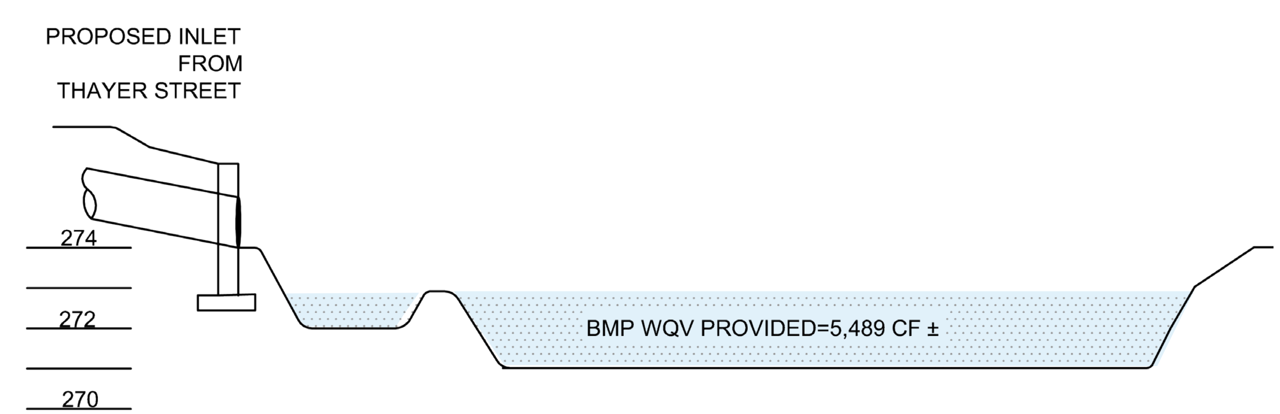
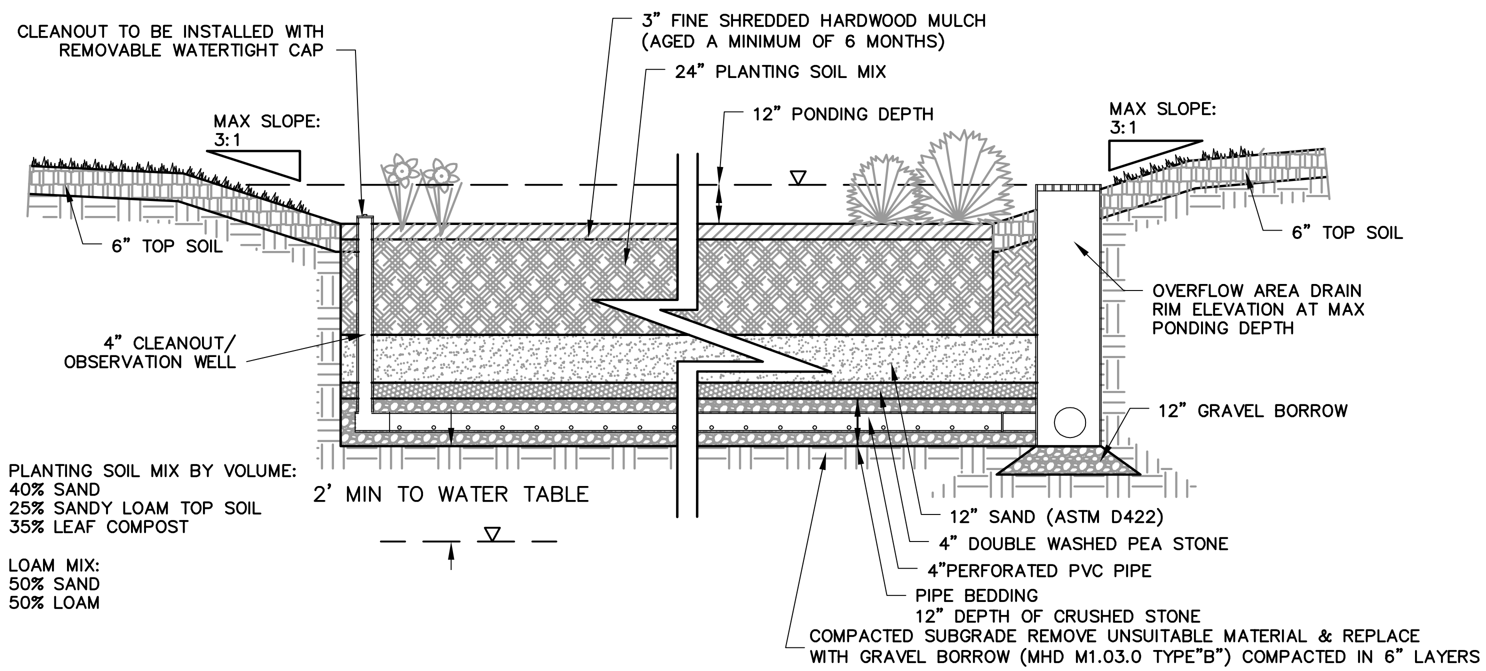


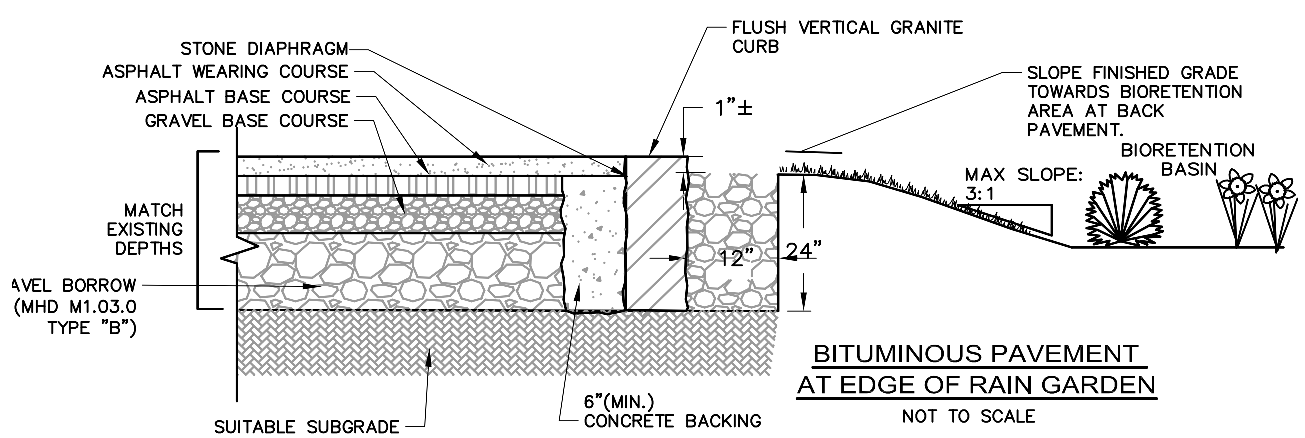
Details provided by Nitsch Engineering

DD1-A BELLINGHAM PLAZA, LLC: BIORETENTION BASINS



RAIN GARDEN (RG)

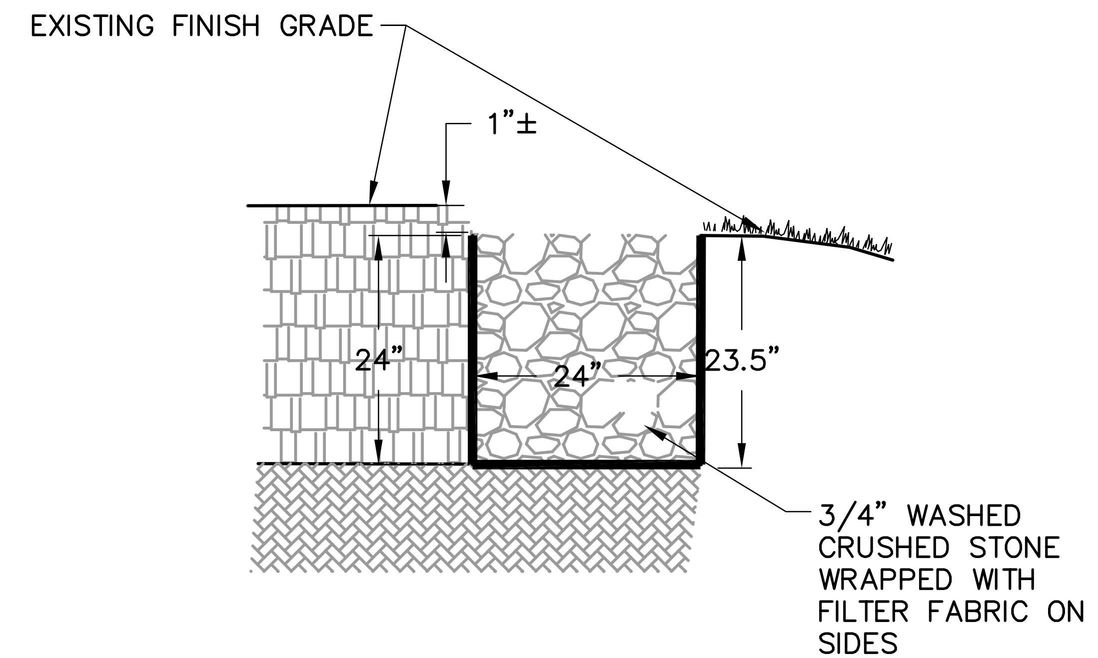
NOT TO SCALE



BITUMINOUS PAVEMENT AT EDGE OF RAIN GARDEN

NOT TO SCALE

DD1-A BELLINGHAM PLAZA, LLC: INFILTRATION TRENCHES

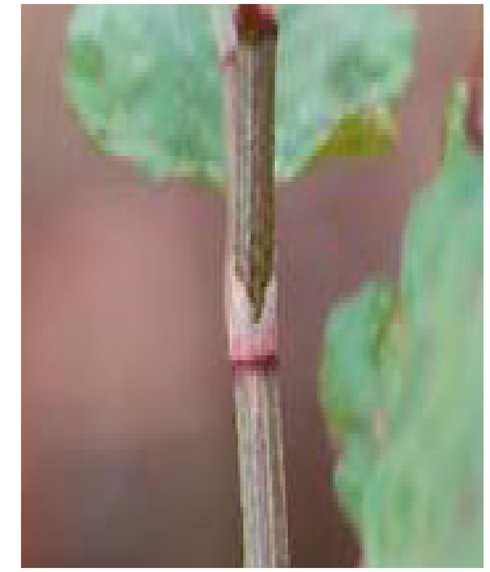


INFILTRATION TRENCH (T)

NOT TO SCALE

Details provided by Nitsch Engineering

The following guidance for control of invasive Japanese Knotweed is excerpted from the Penn State University vegetation management fact sheet, which can be found at: http://vm.cas.psu.edu/Publications/CREP_WS_4_POLCU.pdf



Japanese Knotweed at the O6 drainage basin

Invasive species in Massachusetts are a significant threat to biodiversity, as they displace native species, cause significant changes in habitat and soil structure and exacerbate riparian erosion.

Field studies of the Bellingham subwatershed region observed the presence of several invasive plant species, most notably in the O6 Toni/Jamie Drive drainage basin, where a substantial crop of Japanese Knotweed (Fallopia japonica) threatens to overtake the wetland ecosystem adjacent to the Town Commons.

Removal of invasive Knotweed must be done programmatically; that is, cutting it once will not produce successful results. Aggressive mechanical controls, including cutting/removing plants twice monthly from April through August, should be considered in conjunction with careful integration of herbicide should be considered. Because the plant spreads easily downstream by water, it is necessary to begin control from the furthest possible upstream location. Outreach to all public and private landowners, and the community at large, will increase the success of control.

Knotweed Control Measures

To control knotweed, the rhizome system must be managed. To bring a knotweed infestation to a manageable level, multiple treatments over the course of at least two years must be implemented.

This approach relies on depletion of the reserves stored in the rhizomes in the late spring, and injury through use of systemic herbicides in the late summer. A late summer application of the herbicide glyphosate is one of the most effective treatments available. It also has the advantage of having no soil activity,reducing the risk of injury to non-target plants through root absorption, particularly in riparian forest buffer plantings. If glyphosate contacts the foliage of non-target plants, they will be injured or killed. In the state of Massachusetts, all workers involved in any aspect of handling, mixing and/or loading glyphosate products must be trained as a handler or have a pesticide license.

There are many glyphosate products available. When working in riparian settings, a formulation labeled for aquatic applications is the best choice. The best-known example of this type of glyphosate product is 'Rodeo'.

There are two features that distinguish 'Rodeo' from products labeled only for terrestrial use, such as 'Roundup Pro'. 'Rodeo' has no surfactant, so you must add one; and 'Rodeo' is 1/3 more concentrated than 'Roundup Pro', so only 3/4 the product will achieve the results as a larger dose of 'Roundup'. By using a glyphosate product and surfactant labeled for aquatic settings, the risk of injury to aquatic organisms is greatly reduced. The surfactant in the 'old' Roundup (now sold as 'Roundup Original') was highly toxic to aquatic organisms. Using 'Rodeo' does not permit you to treat weeds in the water or allow you to direct spray into the water: using an aquatic-labeled product close to water simply reduces the risk to non-target aquatic organisms.

A late summer glyphosate application is much easier if the knotweed is mowed or cut around June 1. The regrowth after cutting at this date is much shorter than the original growth - 3 to 4 feet tall rather than the typical 6 to 10 feet of growth. This shorter canopy is much easier to treat with a sprayer: it is less work, and you can be much more selective in the application.

If the knotweed is not cut in June, it should be treated with glyphosate in late July, and then regrowth or missed stems should be spot treated in early September. Follow-up treatment in the second year is essential. You will probably observe 90 to 95 percent reduction in the stand, but if you don't continue to treat it, the knotweed will come back and you will need to start over. Wait until July of the second year for the follow-up treatment. If treatment takes place earlier, there is less translocation of the herbicide to the rhizomes.

Knotweed management is more complex if it's growing among trees. It must be cut earlier and more often to prevent from canopying over tree plantings. As with the single mowing approach, allow at least six weeks after the last mowing before spot treating the knotweed with glyphosate in the late summer. Knotweed may never be eradicated from your site, but it can definitely be kept at a manageable level so it does not impact biodiversity or threaten nearby resources..